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GRAPHITE FIBER REINFORCED THERMOPLASTIC RESINS

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16. Abstract

Mechanical properties of neat resin samples and graphite fiber reinforced samples of thermoplastic resins were characterized with particular emphasis directed to the effects of environmental exposure (humidity, temperature and ultraviolet radiation). Tensile, flexural, interlaminar shear, creep and impact strengths were measured for polysulfone, polyarylsulfone and a state-of-the-art epoxy resin samples. In general, the thermoplastic resins exhibited environmental degradation resistance equal to or superior to the reference epoxy resin.

Demonstration of the utility and quality of a graphite/thermoplastic resin system was accomplished by successfully thermoforming a simulated compressor blade and a fan exit guide vane.

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Graphite Fiber Reinforced Thermoplastic Resins

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SUMMARY

This report describes the results of a one year program designed to characterize the mechanical behavior of graphite fiber reinforced and unreinforced thermoplastic resins. Similar studies were simultaneously performed on an epoxy resin in neat form and reinforced with graphite fibers to enable a comparison between the thermoplastics and a state of the art material intended for structural applications. Particular emphasis was placed on determining the effects of various environmental exposures on the properties of the resins and the composites. In order to accomplish this effeciently, statistically designed tests were utilized throughout the study. Environments investigated included ambient aging, thermal aging at two temperatures, and a combined temperature, humidity, ultraviolet aging. Tension, flexural, shear, impact, and creep properties were measured after various exposure times.

In general it was found that the thermoplastics (polysulfone and polyarylsulfone) exhibited environmental resistance as good as that of the epoxy reference material. In several instances the polyarylsulfone matrix composites suffered less degradation than the epoxy matrix materials. The polysulfone composites were degraded by the thermal aging at the higher temperature (177°C) but suffered little effect as a result of the other exposures. Several properties of the epoxy materials were degraded by the ambient, 177°C, and combined exposures.

Upon completion of the environmental effects study, two complicated gas turbine engine structures, a fan blade and a fan exit guide vane were fabricated using the graphite/polysulfone material. Both parts were successfully made.

1.0 INTRODUCTION

Advanced composites utilizing thermosetting resins as the matrix are becoming increasingly accepted as "engineering materials." Advanced military aircraft will most likely have several airframe structural components in which the materials will be utilized. In the field of gas turbine engines, Pratt & Whitney Aircraft Division of United Technologies Corporation now lists carbon-expoxy as the bill of material for the fan exit guide vanes in the JT9D-59 and-70 engines. The other broad category of resins, the thermoplastics, have received relatively little attention as matrices for structural composites, primarily due to poor elevated temperature mechanical properties. However, developments in the technology over the past few years have resulted in new materials with elevated temperature performance which may match or even exceed that of the epoxies used in the aerospace industry. Furthermore it has been shown that significant cost savings can result in using thermosplastic rather than thermoset matrices as a result of faster fabrication lower rejection rate, lower storage costs, etc. (Ref. 1). In addition their use has led to improvements in composite impact resistance (Ref. 2). However these resins are still largely uncharacterized as structural materials both in neat form and when reinforced with high modulus fibers.

Of particular interest is the effect of environmental exposure on the properties of the materials. Recent experiences with epoxy matrix composites have demonstrated that environmental degradation of critical properties can be a serious problem. Thus there is concern over the effect such exposure might have on the new thermoplastic composites.

As a result of the promise exhibited by this new class of materials and the large number of unanswered questions regarding their performance, United Technologies Research Center (UTRC) conducted the subject program under the sponsorship of NASA-Lewis Research Center.

The objectives of this program were to characterize the mechanical behavior of thermoplastic resins in neat and reinforced form, and to compare this behavior with that of an epoxy resin, typical of those being used in graphite fiber reinforced gas turbine engine fan blades. Particular emphasis was placed on determining the effects of various environmental exposures on these properties. Finally, the thermoforming characteristics of thermoplastic composites were demonstrated by fabricating a graphite fiber reinforced fan blade and a fan exit guide vane.

The program is divided into three technical tasks along the lines of the above objectives. During Task I, two thermoplastic resins and one epoxy resin were tested to determine the effect on tensile and flexural behavior of several environmental exposures including temperature, moisture, and ultraviolet. During Task II,all

resins were reinforced with graphite fibers and tested in the same manner as in Task I. Fabrication of a fan blade and a fan exit guide vane from the better thermoplastic matrix material as defined by Task II was carried out in Task III.

The experimental procedures employed during this program and the results derived from it are discussed in the following sections.

2.0 TASK I - RESIN CHARACTERIZATION

The objective of this task was to measure the mechanical behavior of two thermoplastic resin materials and one commonly-used epoxy. The performance of the materials were then to be compared in order to judge the thermoplastics relative to a state-of-the-art resin matrix material.

2.1 Experimental Procedure

2.1.1 Test Plan

The two thermoplastics evaluated under the program were Astrel 360 polyarylsulfone and P-1700 polysulfone. The epoxy reference material was PR-286.

The majority of the mechanical tests performed on each of the three resins is given in Table I. As a result of the large number of specimens required to measure each of the properties, a Latin Square design was utilized to conduct the study of all but the as-fabricated resins. For the as-fabricated condition, two tensile and two flexure specimens were tested at each of the three test temperatures.

The Latin Square design for the remaining properties of each resin in Table I is similar to the following example:

		Exposure Time		
		C_1	C_2	C_3
Test Temp.	R_1	T_2	T_3	T_1
	R_2	T_1	T_2	T_3
	R_3	T_3	T_1	T_2

The letters $R_{1,2,3}$ correspond to test temperatures of -55°C, 22°C, and 177°C, respectively, while the exposure times are 720, 1440, and 2400 hrs. The letters $T_{1,2,3}$ in the cells of the above matrix correspond to exposure conditions, (HA; ambient; HA, RH, UV), and represent a randomly chosen assignment for the first test (i.e., first row) while the 2nd and 3rd rows are permutations of the first row constrained to the condition of a Latin Square design.

Other properties measured on the neat resins included the glass transition temperature and creep characteristics before and after 1000 hrs of exposure to heated air (177°C), ambient temperature and humidity, and the combined UV/elevated

temperature/humidity environment. The creep tests were to be conducted at 177°C and at a stress equal to 50 percent of the zero time 177°C ultimate strength.

2.1.2 Materials

For the purpose of resin evaluation the P-1700 was procured in sheet form, while the Astrel 360 was obtained as a molding compound and the PR-286 was solution with MEK. Thus, it was necessary to further process the latter two materials into suitable form for testing. The procedures utilized are described below:

Astrel 360

1. Heat powder in oven for 2 hrs at 100°C to remove moisture.

2. Preheat press to 400°C.

3. Place mold in press and monitor temperature with thermocouple. When mold temperature reaches 344°C (~4 min) apply 3.44 MN/m^2 (500 psi) and hold for 40 sec.

4. Cool to 260°C under pressure.

5. Remove mold from press, and remove resin molding as soon as possible.

PR-286 (74% solution in MEK)

1. Heat at 80°C under 30 in. Hg vacuum for about 30 min until rapid bubbling stops.

2. Increase temperature to 115°C and hold for 15 min, then release vacuum.

3. Increase temperature to 125°C and hold for 3 hrs.

4. Increase temperature to 150°C and hold for 16 hrs.

5. Increase temperature to 175°C and hold for 2 hrs.

2.1.3 Test Techniques

Tension specimens were 22.5 cm long x 1.9 cm wide x .25 cm thick (9 in. long x 3/4 in. wide x 1/10 in. thick) with a reduced section 1.25 cm (1/2 in.) wide. Tests were carried out at a crosshead speed of .125 cm/min (0.05 in./min) and strain was measured with strain gages bonded to the front and back of the specimen to average out any bending effects.

Bending tests were conducted using 3-point loading conditions at a span-to-depth ratio of 16:1. Mid-point deflection of the specimen was measured with a deflectometer and the resulting load-deflection curve was used to calculate a bending modulus.

Creep/stress-rupture tests were conducted at 177°C on samples in the as-fabricated condition and on those which have been subjected to environmental exposures for 1000 hrs. Testing was done in constant load machines, the temperature being monitored with chromel-alumel thermocouples positioned adjacent to the specimen. Friction type grips were used with copper doublers to protect the specimen surface. Elongation was continuously recorded during the creep tests by means of an extensometer activated LVDT. The extensometer was attached to the grips holding the specimen. When fracture occurred the machines shut off automatically, and the time to rupture was recorded to the nearest 0.1 hr.

The glass transition temperature (Tg) of the resins was determined through measurement of thermal expansion. The Tg was defined by the intersection of tangents drawn at the point of inflection of the expansion vs temperature. The test specimens were .5 cm x .6 cm x 2.54 cm long (.2 in. x .2 in. x 1 in.). Heating rate during the tests was approximately 45°C per hour.

The resin materials were exposed to three environmental conditions in the program. Ambient conditions were those which exist in the laboratory at UTRC: 22°C, 50 percent RH. An air circulating oven was used for the heated air exposures. The temperature of 177°C was monitored with a thermometer immediately adjacent to the specimens. The final exposure condition was a combined humidity, temperature, ultraviolet. The selected temperature was 49°C and the relative humidity was 95 percent. Ultraviolet exposure was provided by placing the specimens 61 cm from a UV lamp. Specimens were turned over halfway through their exposure period.

2.2 Results and Discussion

2.2.1 Tensile and Flexure Tests

The results of testing the three resins in the as-fabricated condition are given in Table II. In some instances premature failure occurred in the tensile tests due to defects in the specimens and the data were not reported. In general the results of the duplicate specimens were in good agreement, indicating uniformity of the materials.

Several points are apparent, based on these results. The Astrel 360 demonstrated the best resistance to elevated temperature. At lower temperatures the strengths of all three materials were similar, while the PR-286 exhibited higher moduli. The P-1700 polysulfone was apparently in a rubbery condition at the 177°C test temperature and had essentially zero strength and modulus. The PR-286 epoxy also had low properties at 177°C. It should be pointed out that in order to develop maximum temperature resistance, the resin manufacturer recommends a postcure at 200°C for composites utilizing PR-286 as the matrix. However, it has been UTRC's experience that such a postcure can result in cracks in multidirectional composites due to thermal stresses. Thus, a lower postcure temperature was selected for this program (177°C), with the probable result that the resin properties at 177°C were not the maximum achievable.

The resin data generated under the designed test matrix are given in Appendix A using the Latin Square nomenclature described previously. Utilizing those results the effects of each of the time, test temperature, and exposure conditions was estimated for the four properties measured: flexural strength, flexural modulus, tensile strength, and tensile modulus. These effects are given in Tables III through VI. The model employed in the analysis is:

$$Y_{ijk} = \hat{\mu} + R_i + C_j + T_k$$

where

Y_{ijk} = property of interest as effected by the factors, i, j, and k
$\hat{\mu}$ = the mean
R_i = test temperatures
C_j = exposure times
T_k = environmental conditions

As an example of how this can be used, Tables VII, VIII and IX list the calculated flexural strengths for the three resins as a function of exposure time and test temperature for each of the three environmental conditions. The data given for zero exposure time are the averages calculated from the as-fabricated results listed in Table II. The effects of the variables on the other resin properties were also calculated and are given in Appendix B along with the flexural strengths for completeness.

The trends in the data are more easily interpreted by plotting the results as a function of exposure time, for example, as in Figs. 1 thru 3 in which the room temperature flexural strengths of the three resins are shown for the three different environmental conditions. From Fig. 1 it can be seen that the flexural strength of the PR-286 epoxy was significantly degraded by the 177°C exposure while the other two resins were essentially unaffected. Figures 2 and 3 indicate that the ambient and the combined HA, RH, UV exposures did not have a serious effect on any of the materials although the PR-286 epoxy and the Astrel 360 polyarylsulfone were slightly degraded by the temperature, humidity, UV conditions.

Similar plots were constructed for each combination of mechanical property, test temperature and environmental exposure using the calculated properties listed in Appendix B. Examination of these plots led to the following conclusions regarding the effects of the exposures on the measured properties:

Ambient Exposure

	Flexural Modulus	Flexural Strength	Tensile Modulus	Tensile Strength
P-1700	No Effect	Slight drop @-55°C	No Effect	Drop @-55°C
360	No Effect	Slight drop @-55°C	No Effect	Drop @ R.T., -55°C
PR-286	No Effect	Slight drop @-55°C	No Effect	Drop @ R.T., -55°C

HA, RH, UV Exposure

	Flexural Modulus	Flexural Strength	Tensile Modulus	Tensile Strength
P-1700	No Effect	Slight drop @ R.T., -55°C	No Effect	Drop @-55°C
360	No Effect	Slight drop @ R.T., -55°C	No Effect	Drop @ R.T., -55°C
PR-286	No Effect	Slight drop @ R.T., -55°C	No Effect	Drop @ R.T., -55°C

177°C Exposure

	Flexural Modulus	Flexural Strength	Tensile Modulus	Tensile Strength
P-1700	No Effect	No serious effect	No Effect	Drop @-55°C
360	No Effect	No serious effect	No Effect	Drop @ R.T.
PR-286	No Effect	Drop @ all temps.	No Effect	Drop @ R.T., -55°C

The flexural strength data shown in Figs. 1, 2, and 3 are reflected in the comments regarding flexural strength for the 177°C exposure in which the PR-286 suffered a drop at all test temperatures including room temperature as shown in Fig. 1. On the other hand the P-1700 and 360 showed no major effect as indicated above.

The above summary of the environmental effects clearly leads to the conclusion that the two thermoplastic resins exhibited environmental resistance at least as good as that of the epoxy. None of the materials suffered any loss in modulus due to the exposures. The ambient and HA, RH, UV exposures affected the strength properties of all the resins in about the same manner although the P-1700 tensile strength was unaffected at room temperature while the other two resins showed a decrease. The 177°C exposure had a significant effect on nearly all the epoxy flexural and tensile strength properties, while there was very little effect on the two thermoplastics. This was somewhat surprising since the PR-286 is considered to be capable of performing as a matrix material at 177°C service temperature. Although the cure cycle employed in the study was not optimum for high temperature resistance, as mentioned previously, it would seem that the 177°C exposure would serve as a postcure condition, and that the strength properties might even increase. However the data showed a clear trend in the other direction as evidenced by Fig. 1.

2.2.2 Glass Transition Temperature

The results of the glass transition temperature studies are summarized in Fig. 4. All tests were conducted in duplicate and the data in Fig. 4 are the averages of the two measurements. The only environmental condition which had a significant effect on the PR-286 epoxy was the combined temperature, humidity, UV. Based on these results there should have been a large reduction in modulus of the PR-286 when measured at 177°C after the HA, RH, UV exposure. However this was not noted in the previous section. Examination of the tensile and flexural modulus data at 177°C reveals that the results for the resin in the as-fabricated condition were so low as to imply that the test temperature exceeded the T_g of the material. Thus the environmental exposure could not be expected to have a degrading effect. The conflict in the data appears to be between the T_g and modulus measurements at 177°C for the as-fabricated resin. Based on the T_g results, the material should have had a reasonably high modulus at 177°C. It should be pointed out that a true glass transition temperature does not exist for the epoxy since it is a cross-linked material. Inflection points in the thermal expansion curves were indicative of a gradual softening rather than a sharp transition. There was, however, a readily detectable inflection point in the curves for the specimens exposed to the HA, RH, UV condition, and the softening temperature was clearly lower than for the resin in the as-fabricated condition.

None of the exposures had an effect on the T_g of P-1700 polysulfone. The 360 polyarylsulfone suffered a slight decrease in T_g after all three exposures, but none were as severe as the change exhibited by the epoxy.

In summary the glass transition measurements showed that the thermoplastics performed the same as the epoxy under the 177°C and ambient conditions, and that they were also relatively unaffected by the HA, RH, UV exposure whereas the epoxy suffered a loss in T_g under that condition.

2.2.3 Creep/Stress Rupture

The results of the creep/stress-rupture tests on the neat resin specimens are given in Table X. Some difficulties were encountered in the creep/stress-rupture tests. The P-1700 polysulfone had no resistance to stress at 177°C, which was not surprising in view of the previous finding that the resin had essentially zero tensile strength at that temperature. Two tests were conducted on as-fabricated PR-286 epoxy. In the first case (No. 28) the specimen failed immediately upon the application of 50% of the as-fabricated UTS (4.15 MN/m^2), however it appeared that the fracture initiated at a void in the specimen. The second specimen (No. 27) was subjected to the same stress and did not rupture after 621 hrs. The stress level was then increased to 75% of the as-fabricated UTS and failure did not occur after 189 hrs of testing. The stress level was subsequently increased several times before rupture finally occurred at a stress more than three times greater than the static strength of 177°C. Based on these results, it was clear that the stress-rupture behavior of the material was governed by flaws or some other mechanism not necessarily related to the inherent properties of the material. The two specimens exposed to the humidity, temperature, UV condition exhibited a similar scatter in behavior.

The Astrel 360 was somewhat better behaved. All the specimens ruptured under the load which was 50% of the static strength. This stress was significantly higher than that utilized in the PR-286 tests, so a direct comparison of the results is difficult. Examination of the 360 data indicates that none of the exposures had an adverse effect on the stress-rupture behavior of the resin. However there was a large scatter in the results and it would seem that further work should be conducted in this area.

The effect of the 177°C exposure on the creep behavior of the two resins is shown in Figs. 5 and 6. The rapid increase in strain of the PR-286 at 24 hrs (Fig. 5) is believed to be the result of an extensometer malfunction. The steady state creep rate of the cross-linked epoxy was less than that of the thermoplastic polyarylsulfone.

3.0 TASK II - COMPOSITE CHARACTERIZATION

The objective of this test was to evaluate composites having each of the three resins studied during Task I as matrices. The reinforcement for all composites was to be graphite filament. Based on the results of this task and Task I, a single carbon/thermoplastic system was to be selected for the Fabrication Study in Task III.

3.1 Experimental Procedure

3.1.1 Test Plan

Both unidirectional and cross-ply 0°/90° laminates were evaluated. Table XI presents the tests required for the unidirectional composites. As with the neat resins, a statistical approach was followed to produce the desired information while minimizing the number of specimens actually tested. The test matrix for Task II specified four environmental conditions, four test temperatures, but only three exposure times. The balance needed for the Latin Square design was achieved by adding one additional exposure time resulting in a 4 x 4 Latin Square design. The setup was as follows:

Let the environmental conditions be the treatments:

T_1 = heated air, 177°C
T_2 = heated air, 121°C
T_3 = ambient temp., 22°C
T_4 = HA/RH/UV

Let the exposure times be the columns:

C_1 = 720 hrs
C_2 = 240 hrs (added to determine short term effects)
C_3 = 1440 hrs
C_4 = 2400 hrs

Let the test temperatures be the rows:

R_1 = -55°C
R_2 = 22°C
R_3 = 121°C
R_4 = 177°C

The Latin Square for the P-1700 matrix composites was

		Exposure Time			
		C_1	C_2	C_3	C_4
	R_1	T_3	T_4	T_1	T_2
Test Temp.	R_2	T_1	T_2	T_4	T_3
	R_3	T_4	T_3	T_2	T_1
	R_4	T_2	T_1	T_3	T_4

A similar matrix was used for the Latin Square designs of the other two composites, but with different sets of treatment assignments to the cells in the matrix.

In addition to these tests on unidirectional composites, the tensile properties of the 0/90° laminates in the as-fabricated condition were determined at room temperature, 121, and 177°C. The loading direction was in the 45° direction.

The creep/stress rupture properties of the 0/90° laminates were determined at 121 and 177°C for laminates in the as-fabricated condition and for laminates having been exposed for 1000 hrs to heated air (177°C), ambient temperature and humidity and to combined elevated temperature/relative humidity/ultraviolet environment. The load orientation for the creep tests was 45°. The loads for the creep/stress-rupture tests at 121 and 177°C were to be 50 percent of the ultimate loads at the respective temperatures.

The tensile strength in the 45° direction was determined at room temperature and 121°C for 0/90° laminates which had been exposed for 1000 hrs at 121°C in air and subsequently thermally cycled for 1000 cycles between -55 and 177°C.

The Charpy impact strength was determined at room temperature and 121°C for 0/90° laminates in the as-fabricated condition and for laminates which had been exposed for 1000 hrs at 121°C in air, at ambient temperature and relative humidity and at the combined elevated temperature/relative humidity/ultraviolet environment.

3.1.2 Materials

During the second task of the program, the same resins evaluated in Task I were reinforced with T-300graphite and studied in composite form. Commercial prepreg tape was used with the PR-286 epoxy, while prepregs were wet-wound in the laboratory for both the thermoplastics. In both cases a mixture of the resin was

prepared and the T-300 yarn was passed through it and wound on a drum. For the P-1700 50g of resin was dissolved in 400 ml dichloromethane. The solvent for the polyarylsulfone was DMF in a ratio of 200 ml to 20g resin. The resin did not dissolve in the DMF, but formed a fairly stable suspension.

Hot pressing of the P-1700 material was carried out at 270°C under 13.8 MN/m^2 (2000 psi), while the conditions for the Astrel 360 were 371°C, 6.9 MN/m^2 (1000 psi) Each material was held under maximum pressure for five minutes then cooled as rapidly as possible (water-cooled platens) under pressure. PR-286 epoxy composites were pressed under 2.07 MN/m^2 (300 psi) and the cure/postcure temperature cycle was the same as that used for the neat resin.

3.1.3 Test Techniques

The test techniques used for composite evaluation were generally the same as those used for the resin materials in Task I. The tensile test specimen for composites was somewhat different from that used for resins. For unidirectional composites tested in the longitudinal direction, the specimen was straight sided, 15.2 cm long x .64 cm wide x .076 cm thick (6 in. x 1/4 in. x .030 in.). Fiberglass tabs were bonded on both ends for gripping. The transverse tensile specimen was 10.2 cm long x 1.28 cm wide x 0.191 cm thick (4 in. x 1/2 in. x .075 in.). Short beam shear specimens were .64 cm wide x .254 cm thick (1/4 in. x 1 in.) and were tested at a span-to-depth ratio of 4:1.

Tensile specimens for the cross-plied composites were similar to the transverse tensile specimen, but were 15.2 cm long (6 in.). This same specimen was used for creep and thermal cycling tests of cross-plied materials. Thermal cycling test specimens were raised into a furnace then lowered into a cooling zone to produce a thermal cycle over the temperature range of interest. Cyclic rate was about 12 per hour. A total of 1000 cycles was applied to each specimen and damage was measured through visual inspection and a post-test tension test to determine any changes in modulus and strength. Specimen dimensions were those used in the static tensile test.

The impact test was of the pendulum type (instrumented). The instrumented test is far superior to the standard test since it provides much more information regarding material behavior. Specimen dimensions were 5.5 cm long x 1 cm wide x 1 cm thick (2.165 in. x .394 in. x .394 in.). All specimens were unnotched.

3.2 Results and Discussion

3.2.1 As-Fabricated Data

The results of the tests on unidirectional composites in the as-fabricated condition are presented in Tables XII and XIII.

The flexural data reveal that the epoxy matrix composite had superior properties at the lower test temperatures. However, at 121°C all three materials had essentially the same strength and modulus, while at 177°C the Astrel 360 composites were the best. The flexural properties of the Astrel 360 appeared to be insensitive to test temperature over the range studied.

Similar results were apparent in the short beam shear tests in which the PR-286 matrix materials exhibited the highest strength at lower temperatures, but the Astrel 360 was the best at 177°C. The transverse tensile strengths at room temperature indicate that the epoxy formed a stronger interfacial bond than either of the thermoplastics. However, the superior high temperature strength retention of the Astrel 360 was demonstrated by the test results at 177°C, where those composites had higher strengths and moduli than the PR-286 matrix materials. The P-1700 matrix composites had zero strength at that temperature. In general, the tensile data followed the trend established by the other testing. In terms of strength retention the 360 matrix materials were the least sensitive to the effects of temperature, while the P-1700 matrix composites were the most sensitive. The best strength properties at lower temperatures were with the epoxy matrix composites, but this may have been due to better fiber properties in the prepreg.

The same general conclusions appear valid regarding the tensile data on cross-plied composites as shown in Table XIV. In this instance the better room temperature strength of the PR-286 composites can be attributed to a better fiber-matrix interfacial bond since the specimens failed along those planes. The elevated temperature properties of the 360 matrix specimens were again the best of all the materials.

The Charpy impact strengths of both thermoplastic composites were insensitive to test temperature up to 121°C. Apparently at that temperature the plasticity of the resin had not increased sufficiently to absorb additional energy. Load-deflection curves obtained for the materials during the impact tests indicated that the behavior of the Astrel 360 composites was essentially linear at both test temperatures while the P-1700 composites exhibited some plasticity. The PR-286 was the poorest material at room temperature but was essentially equivalent to the 360 composites at 121°C. The P-1700 composites had the best impact resistance at both test temperatures. Typical load-time curves from the instrumented tests are presented in Figs. 7 and 8 for room temperature and 121°C test temperatures, respectively. Comparison of the PR-286 composite curves at room temperature and 121°C indicates that failure mode changed from abrupt rapid crack propagation, characterized by a sharp drop in load to a combined delamination/tensile crack propagation characterized by the intermittant drops then relatively constant load carrying ability.

It was found necessary to modify the creep/stress-rupture test plan for cross-plied specimens in the as-fabricated condition. Two specimens were to be tested for each condition; one for creep behavior and one for stress-rupture. The original

intent was to conduct the tests at a stress level 50% of that measured at the temperature of interest under static conditions. As the data in Table XV. show, almost all the specimens ran for excessive periods of time at that stress. In order to obtain failures in a reasonable time period, the stress level for several specimens was increased as indicated in the table.

3.2.2 Environmental Effects on Static Properties

The composite data obtained under the statistically-designed test program are presented in Appendix C. From this information the effect of each of the exposures on the seven measured composites was estimated and the data are presented in Tables XVI through XXII. As with the resin data, in order to determine the effect of a given combination of test temperature, exposure time and environmental condition, the appropriate factors are added to the mean for the material of interest. As an example, Table XXIII presents the calculated composite shear strengths after the exposure to heated air (177°C). The zero exposure time data are the as-fabricated results. Appendix D is a full listing of all calculated composite properties which were part of the statistically designed test program.

The data in Table XXIII are shown graphically in Figs. 9, 10, 11 and 12 in which the shear strength at each of the four test temperatures is plotted as a function of exposure time at 177°C. Based on the curves the following conclusions were reached:

1) The exposure had very little effect on the shear strength of Astrel 360 matrix composites regardless of test temperature and exposure time.

2) The elevated temperature shear strength retention of the Astrel 360 matrix composites was the best of the three materials.

3) The P-1700 polysulfone and the PR-286 epoxy composites behaved in a similar manner although the absolute values for the epoxy composites were generally better.

Another method of examining the data is to determine the relative effects of the four exposures on a given composite property. Figures 13, 14 and 15 along with Fig. 11 illustrate the effect of the exposures on the composite shear strength as measured at 121°C. All four exposures had the same effect on a qualitative basis in that there was some degradation of the PR-286 epoxy and the P-1700 polysulfone systems, while the Astrel 360 polyarylsulfone matrix composites were unaffected as a function of exposure time. In several instances there was a good deal of scatter in the statistically predicted results, and the curves were drawn to fit the overall trend in the data. This practice was followed in the analysis of all the data, i.e. the overall trend over the 2400 hr exposure was examined. The lack of effect of the various environments on the shear strength of the Astrel 360 matrix composites is very encouraging, however in many instances the absolute strengths were no better than those of the other systems. In order for the Astrel 360 composites to show clear advantage, the relatively low as-fabricated shear strength must be improved.

The effects of the four environments on 121°C composite flexural strength are presented in Figs. 16 through 19. The results shown in Fig. 16 indicate that the flexural strength of the P-1700 composites was very slightly degraded after long exposures at 177°C. The PR-286 and Astrel 360 strengths were somewhat increased by the thermal aging. The 121°C exposure produced a slight increase in the flexural strength of all the materials.

The ambient and RH, UV, temperature conditions had similar effects on the composites as shown in Figs. 18 and 19. The P-1700 composites showed no net change after 2400 hrs while the Astrel 360 polyarylsufone and the PR-286 epoxy flexural strengths increased.

The flexural moduli of the composites responded much the same as the strengths as a result of the two elevated temperature exposures as shown in Figs. 20 and 21. None of the systems was adversely affected by the ambient or humidity exposures given in Figs. 22 and 23.

Plots were constructed to graphically illustrate the effect of each environmental exposure on each of the seven properties measured at each of four test temperatures for the three composite systems. As discussed above several of the curves exhibited scatter in the data as a function of exposure time. It is possible that these were real effects and the properties went through maxima and/or minima at times less than the full exposure of 2400 hours. However such detailed analysis was beyond the scope of this program and the results reported herein are the net effects or trends in the data over the full 2400 hr exposure period.

Summaries of the analysis of the results for each of the properties measured are given in Tables XXIV through XXX. In reviewing these results, it was found convenient to consider groups of properties which would be expected to respond to environment in a similar manner as a result of the properties being controlled by a common factor. Thus longitudinal flexural and tensile modulus were grouped as were transverse tensile strength and short beam shear strength, and longitudinal tensile and flexural strength. The commonality in the final grouping was based on the assumption of a tensile failure mode in the flexural test. The seventh property transverse tensile modulus should be strongly dependent on the behavior of the matrix and the results might be expected to correlate well with the Task I results for resin modulus.

A great deal of similar response to environment was found in the longitudinal modulus properties. These properties which are strongly dominated by the reinforcing filaments would be expected to be rather insensitive to environmental effects. Possible mechanisms for changes would most likely involve changes in the matrix to such a degree that stress transfer capability would be markedly altered. It was found that the ambient and heated air (121°C) exposures had no effect on the composite moduli regardless of test temperature. The heated air (177°C) exposure degraded

the tensile and flexural moduli of the P-1700 matrix composites at all test temperatures. This may have been due to interfacial degradation since Task I studies showed the resin modulus was affected only at -55°C test temperatures. The moduli of the other two composites were unaffected by the 177°C exposures.

The only point of disagreement between the effects of environment on the two moduli was regarding the humidity/temperature/UV condition. There was no effect on the flexural moduli of any of the composites. Tensile moduli of the PR-286 matrix composites were degraded at all test temperatures. However in all cases the calculated values were constant as a function of exposure time for the 240, 720, 1440 and 2400 hr exposures, but lower than the as-fabricated measured value by 25-35%. In view of the flexural modulus results it seems likely that some unaccounted factor affected the predicted results and the observed decreases were not caused by the environmental exposures but by some uncontrolled test variable.

In summary, the longitudinal tensile and flexural moduli were generally not affected by the environmental conditions investigated. The one exception was the P-1700 matrix composites under the 177°C exposure. However this is not a very significant observation since testing of materials in the as-fabricated condition previously indicated that P-1700 matrix composites are not useful for 177°C structural applications.

The composite shear strength and transverse tensile strength also responded in a similar pattern to the environmental exposures. In this instance the performance of the matrix plays an important role in composite behavior since both properties are largely controlled by matrix and/or interface strength characteristics.

The ambient exposure had little effect on the transverse tensile strengths of the composites. The only exception was the PR-286 matrix composite when tested at -55°C which resulted in an indicated loss of 30% of the as-fabricated strength. The effects of the ambient exposure on shear strength were somewhat more severe in that the PR-286 composites were affected at all test temperatures with the largest effect measured at 121°C where 45% of the original strength was lost. At the 20°C test temperature there was a 10% reduction. The data were somewhat confusing at the 177°C test temperature in that the calculated values indicated a clear downward trend in strength as a function of exposure time. However the as-fabricated strengths were approximately the same as the 2400 hr exposure value, so there was only a slight net change in the strength. It is possible that the as-fabricated 177°C shear strengths were in error (they were lower than anticipated) and that the ambient exposure had a degrading effect on the 177°C shear strength of the PR-286 matrix composites.

The only other indication of an effect of ambient exposure on shear strength was with the P-1700 matrix composites. The 121°C shear strength was slightly reduced as a function of exposure time. The 177°C results were somewhat similar to those of the PR-286 composites. The calculated values showed a downward trend

but the value calculated for the 2400 hr exposure was actually somewhat higher than that measured for the composite in the as-fabricated condition. In this case there was no reason to suspect the as-fabricated measurement since poor strength retention of P-1700 at 177°C had been previously demonstrated. Thus it seemed reasonable to conclude that no significant effect resulted from the ambient exposure of the P-1700 composites. The Astrel 360 matrix composites were unaffected at all test temperatures.

The humidity/temperature/UV exposure produced results generally similar to those of the ambient exposure. The transverse tensile strength of the PR-286 composite was reduced at all test temperatures as was the shear strength. Thus the exposure was more severe on the PR-286 composites than the ambient which produced a reduction in the -55°C strength only. The transverse tensile strength of the P-1700 matrix composites was unaffected by the exposure at three lowest test temperatures, while the Astrel 360 composites were slightly degraded at the three highest test temperatures.

The shear strength of the PR-286 and P-1700 composites underwent the same changes as the transverse tensile strength. The Astrel 360 was less affected, showing only a slight loss in 177°C shear strength.

The 177°C exposure resulted in large reductions in both transverse tensile and shear strengths for the P-1700 composites at all test temperatures. The shear strength of the PR-286 composites showed the same losses, but the transverse tensile strength was less affected, although significant losses were calculated for the -55°C and 177°C test temperatures. The Astrel 360 composite was not affected by the exposure with the exception of the 177°C transverse tensile strength which was reduced to zero. This was not too significant since the as-fabricated value was only 6.9 MN/m^2 (1ksi).

The important conclusion which can be drawn from the transverse tensile and shear strength data is that with the exception of the 177°C exposure, both thermoplastic composites performed at least as well as the epoxy matrix composite. The 177°C exposure caused severe degradation of the P-1700 composite properties but this was not suprising. The Astrel 360 matrix composites performed as well or better than the epoxy in all instances, and in general the shear and transverse tensile strengths were not affected by the four exposures investigated. The good performance of the thermoplastics is particularly significant because these two properties are probably more easily affected by matrix behavior than the other properties studied in the program.

The next grouping of properties includes the longitudinal strengths, tensile and flexural, which should be primarily controlled by the reinforcing fiber although interfacial bond strength can certainly play an important part, particularly in flexural strength.

It was found that the two properties did not respond in a similar manner in several instances. The tensile strengths of the composites frequently were degraded while the flexural strengths were not. This was unexpected since the other failure modes possible in flexural loading (shear and compression) seemed much more likely to be initiated if degradation of the matrix occurred. If the tensile strength of the materials was actually reduced by the exposures, then the flexural strength should have shown a similar trend. A possible reason for a tensile degradation not showing up in the flexural test is that the entire volume of material is under maximum stress in the tensile specimen, while only the outer surface under the loading nose is at maximum stress in a three-point flexural test. Thus on a statistical basis a degradation in tensile strength might not be as readily detected in the flex test. However for those exposures where moisture and/or UV would be expected to be responsible for any degradation which occurred, effects should be noticed at the surface of the specimen first, and it could be argued that the flexural test would be more sensitive to such changes than the tensile test. A comparison of the data shows this was not the case. For example, the tensile strength of the Astrel 360 matrix composites underwent a substantial reduction after ambient exposure when tested at 20°C, 121°C, and 177°C. The flexural strengths of the composites were actually increased under most of those conditions.

The most reasonable explanation for the discrepancies between the two tests is that the tensile results were occasionally reduced due to experimental error such as grip failure, improper alignment, etc. In general such problems are much more likely to occur in the tensile test. Proper axial loading of highly anisotropic materials is difficult to accomplish. At elevated test temperatures the testing problems are further complicated by the possibility of failure in the adhesive used to bond the doublers to the gripped portion of the specimens. The data may point to this problem because many of the contradictory results occurred at elevated test temperatures.

Such problems do not occur in the flexural test and therefore it is felt that the flexural data more accurately reflect the effects of the environmental exposures on fiber-controlled strength properties. That being the case the only material which was significantly degraded by the exposures was the P-1700 composite. The humidity, temperature, UV exposure caused loss in the -55°C and R.T. strengths, as did the 177°C exposure. The fact that the tensile strength of the composite was not changed by those conditions might point to shear or compression failure modes as the weak link which caused the reduction. The P-1700 composite shear strength data, discussed previously, did not show any degradation as a result of the RH, HA, UV exposure, but did indicate substantial reduction at all test temperatures as a result of the 177°C exposure.

The final property to be considered is the composite transverse tensile modulus. This is primarily dependent on the matrix tensile modulus although filament modulus and volume fraction also play a role. Since the latter two factors would not be expected to vary as a result of environmental exposure, the composite transverse tensile modulus should respond much the same as the resins.

For the most part a comparison of resin and composite performance is possible. The resin data were presented in Section II, and the composite data are given in Table XXX. Regarding the composite results it should be pointed out that all the 360 matrix data were heavily influenced by a strong negative effect for 2400 hour exposures (See Table XVIII). In several instances the data showed no effect of exposure times up to 1440 hours, but the large drop at 2400 hours resulted in an overall downward trend. Although there is no reason to suspect the validity of the 2400 hour effect other than its abruptness, the Astrel 360 matrix results would have been much better were it not for that single factor.

Taking the composite results as they stand the Astrel 360 matrix materials were degraded a good deal more than the other composites. Substantial losses in transverse tensile modulus were indicated for every exposure. This is definitely contrary to the neat resin data in which there was no change in tensile modulus for any of the conditions. The other composites more nearly reflected the resin results in that there were no significant effects with the exception of the fact that all the materials showed some loss in modulus at the 121°C test temperature for all the environmental exposures. Since the neat resins were not tested at that temperature, no comparison can be made.

Although changes in transverse tensile modulus are probably of secondary importance in most structural applications (since it is quite low to begin with), perhaps further effort should be devoted to examining its response to environmental effects. It is the only property for which all the materials exhibited an across-the-board degradation of property for all the environmental exposures.

There are several important conclusions which can be drawn from the study of environmental exposure of the composites. The P-1700 composites were generally degraded by the 177°C exposure. This, coupled with their poor retention of properties when tested at 177°C, strongly indicates that the material cannot be used in structural applications in which the service temperature is 177°C for a reasonable period of time. Although it was realized that 177°C was slightly above the Tg of the neat resin, it was felt that the high volume fraction filler provided by the filament might raise the use temperature. This was not found to be the case.

Excluding the 177°C conditions for the P-1700 composites, additional conclusions can be reached. None of the composites suffered degradation of fiber-controlled modulus (longitudinal tension and flex). The resin-controlled modulus, transverse tension, was the only property in which the Astrel 360 matrix composites were apparently degraded more than the others. There was some doubt concerning the data in that particular case, and further investigation may be warranted if a loss of transverse tensile modulus is considered significant. The fiber-controlled strength properties (longitudinal tension and flex) were generally unaffected, although the RH, HA, UV exposure resulted in degradation of the P-1700 matrix composites at the lower test temperatures. In the area of matrix or interface-controlled strength,

the thermoplastic matrix composites performed better than the epoxy material. The 360 matrix materials were particularly good in that neither the transverse tensile strength nor the shear strength was significantly degraded by any of the exposures. Both properties were degraded at most of the test temperatures for the epoxy matrix composites.

3.2.3 Environmental Effects on Pendulum Impact

The results of the pendulum impact testing of cross-plied environmentally-exposed composites are plotted in Fig. 24 and 25 for the room temperature and 121°C tests, respectively. Overall the testing indicated no adverse effects due to the exposures. The P-1700 composites had the highest as-fabricated impact strength at both test temperatures, and that ranking was retained after the exposures with the exception of the 121°C test after 1000 hrs of RH, HA, UV. In that case the PR-286 composite underwent an appreciable increase in impact strength and surpassed the P-1700 composite. The PR-286 composites exhibited an increase in impact strength after the RH, HA, UV exposure when tested at both R. T. and 121°C in comparison with the unexposed results. The load-time curves from the tests of the exposed specimens are presented in Fig. 26 for comparison with the curves for the unexposed specimens in Figs. 7 and 8. When tested at room temperature the exposed specimens underwent delamination as evidenced by the intermittant drops in load. This resulted in higher energy absorption and was probably caused by the slight drop in shear strength due to the exposure. Similarly the 121°C curve exhibited more delamination in the exposed specimen than in the unexposed specimen. In addition the initial loading portion of the curve was more nonlinear after exposure, indicating some plasticization of the resin. Both these factors would increase the impact energy.

3.2.4 Thermal Cycling

The results of the tensile tests on composites which were aged for 1000 hrs at 121°C then cycled 1000 times between -55°C and 177°C are summarized in Table XXXI. The as-fabricated data were previously given in Table XIV.

Some difficulty was encountered in thermal cycling of the P-1700 matrix composites. The desired upper temperature was 177°C which is sufficient to cause the P-1700 to soften considerably. As a result of the thermal gradients in the furnace (~10°C) several of the specimens were distorted since one end was above the softening temperature and the other end was below. This resulted in most of the specimens being unsuitable for testing in tension, although one specimen was tested. The thermal cycling tests on the other materials were conducted satisfactorily.

The PR-286 composites were slightly degraded in strength at the 20°C test temperature, but showed an increase at 121°C. In both cases the effect was not large. There was a good deal of scatter in the modulus measurements, but again there seemed to be no significant changes as a result of the exposures.

Due to the problems discussed above, the one test conducted on the P-1700 matrix composite has very little significance. The measurement did not indicate much effect on strength but the modulus appeared to be degraded.

The 360 matrix composites apparently were reduced in strength, especially at the 121°C test temperature where the strengths after exposure were less than half of those in the as-fabricated condition. Modulus values were reduced in a similar manner.

3.2.5 Creep/Stress Rupture

The results of the stress-rupture testing on 0° - 90° cross-plied composites with the three matrix resins are presented in Tables XXXII, XXXIII, and XXXIV. In every case the loading direction was at 45° to the reinforcement direction. As with the neat resin results, the PR-286 composites exhibited a good deal of scatter. For example, specimens 41 and 42 which were both exposed to 177°C for 1000 hrs responded very differently in the stress-rupture test at 121°C. The 121°C tests did indicate degradation in stress rupture life as a result of the exposure to the RH, HA, UV condition. Both specimens essentially failed during initial loading. The 177°C results for the PR-286 composites were complicated by the fact that the specimens did not rupture under the 50 percent UTS load. Specimen 48 finally failed at a stress over 50 percent higher than the static strength at that temperature. Again, this behavior was similar to that experienced with the PR-286 resin.

The P-1700 composite data, Table XXXIII, were more consistent. At 121°C test temperature the 177°C exposure reduced the rupture life to zero for both specimens. This fits with the other data which indicate that the material loses structural integrity at that temperature. The RH, HA, UV environment appeared to increase the stress-rupture life, possibly due to chemical changes caused by the UV. The ambient exposure had little effect on the material. The stress rupture life at177°C was quite short for all the specimens subjected to environmental exposure, again reflecting the unsuitability of the material for use at that temperature.

The 360 matrix composites showed enough scatter to make interpretation of the results difficult. The results did show that the as-fabricated specimens withstood 52.5 MN/m^2 (7.6 ksi) at 121°C for 189 hrs without failure, while the specimens subjected to the RH, HA, UV and ambient environments failed after 62 and 48 hrs, respectively, under the same conditions. The 177°C tests showed much more variation.

Typical creep curves for the 121°C test temperature are presented in Figs. 27, 28, and 29 for the PR-286, P-1700 and 360 matrix materials, respectively. Steady state creep rate for the epoxy composite was much lower than that of either of the thermoplastic composites. This observation is in agreement with similar findings for the neat resins, and leads to the conclusion that creep of thermoplastic matrix composites is an area of concern in stiuations such as those studied under this program, i.e.,

when there are no continuous fibers in the loading direction. It is clear that fibers will always be present in primary load-carrying directions, but secondary stresses could be sufficient to cause the behavior evident in Figs. 28 and 29. This is an area where further work is needed.

4.0 TASK III - FABRICATION OF DEMONSTRATION COMPONENT

The purpose of this task was to study the fabricability of graphite/thermoplastic composites using two gas turbine engine structures as demonstration items. The first was a blade in the configuration of the TF 30 third stage compressor blade. The second was the fan exit guide vane utilized in the JT9D-70 engine. In neither case was there an attempt to actually design a useful structure. Ply configurations were selected based on experience with other composite systems.

4.1 Materials

The prepreg for the fabrication study was prepared by UTRC using the procedures described previously. Material was supplied to Pratt & Whitney Aircraft in the form of prepreg tape, each tape being 152 cm lg. x $11\frac{1}{2}$ cm wide (5 ft. x $4\frac{1}{2}$ in.).

4.2 Blade Fabrication

The steps involved in fabrication of the blade were as follows:

1. Preparation of root blocks and wedge
2. Ply cutting
3. Ply layup
4. Die load
5. Hot press
6. Machining

The root blocks and dovetail wedge were titanium alloy. The wedge was etched with sodium dischromate solution dried, coated with polysulfone solution, then baked for 15 min. at 285°C. Root blocks were solvent rinsed, grit blasted, then coated with polysulfone in a similar manner.

All ply cutting was done in a clean room using cardboard templates and scissors or razor blades for cutting. Ply configuration was of the core-shell type with an outer shell of $\pm 45^\circ$ plies and an inner core of 0° plies. There were a total of 23 plies in the blade, with eight being $\pm 45^\circ$.

Layup was accomplished by thermoforming each ply with a heat gun to the approximate contour required. Polysulfone solution was used to spot bond the plies together. Clamps were applied for a few minutes as each layer was added in order to allow the solvent (methylene chloride) to evaporate in air and bond the plies.

The layup and root blocks were placed in the die then placed in the hot press. The die contained five thermocouples for monitoring temperature during the hot press cycle. After placing the die in the press, contact pressure was applied during the heating cycle which took approximately 50 minutes. Full pressure of 13.8 MN/m^2 (2ksi) was then slowly applied and held for five minutes. The part was cooled to 121^oC under pressure, then removed from the press. Cooling time in the press was about $3\frac{1}{2}$ hrs. Fig. 30 shows the blade after removal from the mold. A small amount of flash is apparent around the leading and trailing edges and the tip, indicating that the entire surface received pressure during the molding operation.

The machining of the airfoil radii and the root was accomplished without problems, and the finished blade is shown in Fig. 31.

4.3 Vane Fabrication

The steps involved in the fabrication of the fan exit guide vane were essentially the same as those followed for the blade. An aluminum leading edge protection strip was integrally bonded in place during the molding operation. The attachment mechanism for the vane involved polyurethane blocks which were molded in place in a secondary dipping operation after the fabrication of the vane. Figure 32 shows two views of the finished fan exit guide vane.

5.0 CONCLUSIONS

Based on the results of this program, the following conclusions have been reached:

- Resin Behavior

The two thermoplastics exhibited environmental resistance as good as that of the epoxy reference material.

The strength properties of all the resins were somewhat degraded by the ambient and the combined humidity, temperature, ultraviolet exposures.

The 177°C thermal aging degraded the strength properties of the epoxy but had little effect on the thermoplastics.

None of the resins suffered any loss of modulus as a result of the environmental exposures.

The glass transition temperature of the epoxy was reduced after the humidity, temperature, UV exposure, while the thermoplastics showed little effect.

P-1700 polysulfone had no creep resistance at 177°C. Further work should be done on creep/stress-rupture to resolve questions which arose from scatter in the data.

- Composite Behavior

Longitudinal moduli (tensile and flexural) were unaffected by the environmental exposures with the exception of the P-1700 composites which were degraded by 177°C aging.

The Astrel 360 polyarylsulfone suffered very little loss in composite shear or transverse tensile strength properties which are controlled by matrix or interface strength. The P-1700 polysulfone composites were degraded by the 177°C exposure, but showed little effect as a result of the other exposures. The shear and transverse tensile strengths of the PR-286 epoxy composites were degraded by the ambient RH, HA, UV, and 177°C environments.

The longitudinal tensile and flexural strength tests produced inconsistent results in that tensile strength of the composites was degraded in several instances where the flexural strength was not. The most reasonable explanation of this apparent contradiction was that the tensile data were erroneous, and that the flexural results

were more representative of fiber-controlled composite strength. That being the case the P-1700 composite was the only system which suffered loss in strength; that occurring as a result of the 177°C and the RH, HA, UV exposures.

The transverse tensile modulus of the Astrel 360 matrix composites was apparently degraded under all exposure conditions. More testing should be conducted to verify this conclusion.

Pendulum impact behavior of all three composites was essentially unaffected by the exposures.

Thermal cycling between -55°C and 177°C resulted in little effect on the epoxy composites. The P-1700 polysulfone composites were severely distorted after the cycling, while the tensile properties of the Astrel 360 composites were significantly reduced. This is the one area where the thermoplastic composites suffered more damage than the epoxy composite.

Creep rates for the thermoplastic composites were higher than that of the epoxy composite. More testing should be conducted to clarify this behavior since there was a good deal of scatter in the results.

- Fabrication

Two complicated gas turbine engine structures, a fan blade and a fan exit guide vane, were fabricated from graphite fiber reinforced polysulfone without problems.

REFERENCES

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2. Novak, R. C.: Materials Varables Affecting the Impact Resistance of Graphite and Boron Composites, Technical Report AFML-TR-74-196, September 1974.

Table I

Task I - Test Matrix for Neat Resins

Property	Exposure Conditions	Exposure Temp. °C		Exposure Time, Hr				Test Temp. °C		
		22	177	0	720	1440	2400	-55	22	177
Tensile Strength and Modulus and Flexural Strength and Modulus	As-fabricated			x				x	x	x
	Heated Air (HA)		x		B	C	D	BCD	BCD	BCD
	Ambient[a]	x			E	F	G	EFG	EFG	EFG
	HA/RH/UV[b]				H	I	J	HIJ	HIJ	HIJ

[a] 22°C, 50% RH

[b] 49°C, 95% RH, 61 cm from UV light

Table II

As-Fabricated Neat Resin Data

Resin	Test Temp. °C	3-Pt. Flexure σ MN/m^2	3-Pt. Flexure σ (ksi)	3-Pt. Flexure E GN/m^2	3-Pt. Flexure E (msi)	Tension σ MN/m^2	Tension σ (ksi)	Tension E GN/m^2	Tension E (msi)
PR-286 Epoxy	-55	163	23.6	4.13	0.598	49	7.1	6.10	0.885
		211	30.6	4.34	0.629	52	7.6	5.73	0.832
	22	139	20.1	3.04	0.440	-	-	4.23	0.613
		130	18.9	3.21	0.465	63	9.1	4.14	0.600
	177	17	2.4	0.29	0.042	5	0.7	0.28	0.040
		19	2.8	0.29	0.042	6	0.8	0.33	0.048
P-1700 Polysulfone	-55	132	19.2	2.33	0.338	-	-	3.10	0.450
		128	18.5	2.31	0.335	77	11.1	3.36	0.488
	22	118	17.1	2.71	0.393	41	6.0	3.08	0.446
		117	16.9	2.56	0.372	51	7.4	3.04	0.440
	177	0	0	0	0	10	1.5	-	-
		0	0	0	0	0	0	0	0
360 Polyarylsulfane	-55	159	23.0	3.58	0.374	53	7.7	3.44	0.498
		163	23.6	2.54	0.368	60	8.7	3.37	0.488
	22	139	20.1	2.65	0.384	57	8.3	2.81	0.407
		145	21.0	2.82	0.408	80	11.6	2.99	0.433
	177	72	10.4	2.48	0.360	17	2.5	2.34	0.339
		56	8.1	2.10	0.304	19	2.7	2.37	0.344

Table III

Estimate of Environmental Effects on Resin
Flexural Strength

	P-1700 Polysulfone		360 Polyarylsulfone		PR-286 Epoxy	
Mean	73.91 MN/m^2	10.72 ksi	106.11 MN/m^2	15.39 ksi	74.26 MN/m^2	10.77 ksi
Rows Test Temps.						
$\hat{R}_1$ (-55°C)	34.10	4.94	21.44	3.11	47.78	6.93
$\hat{R}_2$ (20°C)	39.76	5.68	21.93	3.18	13.03	1.89
$\hat{R}_3$ (177°C)	-73.22	-10.62	-43.37	-6.29	-60.81	-8.82
Columns Exposure Times						
$\hat{C}_1$ (720 hrs)	5.79	0.84	10.96	-1.59	14.20	2.06
$\hat{C}_2$ (1440 hrs)	6.48	0.94	2.34	0.34	-10.82	-1.57
$\hat{C}_3$ (2400 hrs)	-12.27	-1.78	8.55	1.24	-3.31	-0.48
Treatments Environmental Conditions						
$\hat{T}_1$ (177°C)	-9.17	-1.33	9.58	2.68	-43.92	-6.37
$\hat{T}_2$ (ambient)	7.03	1.02	1.24	0.18	32.61	4.73
$\hat{T}_3$ (HA, RH, UV)	2.55	0.37	-19.7	-2.86	11.38	1.65

Table IV

Estimate of Environmental Effects on Resin
Flexural Modulus

	P-1700 Polysulfone		360 Polyarylsulfone		PR-286 Epoxy	
Mean	1.8 GN/m^2	0.26 msi	2.6 GN/m^2	0.37 msi	3.0 GN/m^2	0.44 msi
Rows Test Temps.						
$\hat{R}_1$ (-55°C)	0.97	0.14	0.34	0.05	2.13	0.31
$\hat{R}_2$ (20°C)	0.83	0.12	0.14	0.02	0.07	0.01
$\hat{R}_3$ (177°C)	-1.79	-0.26	-0.55	-0.08	-2.21	-0.32
Columns Exposure Times						
$\hat{C}_1$ (720 hrs)	-0.21	-0.03	0.07	0.01	0.55	0.08
$\hat{C}_2$ (1440 hrs)	0	0	-0.21	-0.03	-0.76	-0.11
$\hat{C}_3$ (2400 hrs)	0.21	0.03	0.07	0.01	0.21	0.03
Treatments Environmental Conditions						
$\hat{T}_1$ (177°C)	0	0	-0.14	-0.02	0.62	0.09
$\hat{T}_2$ (ambient)	-0.07	-0.01	0	0	0.21	0.03
$\hat{T}_3$ (HA, RH, UV)	0.07	0.01	0.14	0.02	-0.83	-0.12

Table V

Estimate of Environmental Effects on Resin Tensile Strength

	P-1700 Polysulfone		360 Polyarylsulfone		PR-286 Epoxy	
Mean	33.30 MN/m^2	4.83 ksi	41.58 MN/m^2	6.03 ksi	21.03 MN/m^2	3.05 ksi
Rows Test Temps.						
$\hat{R}_1$ (-55°C)	10.96	1.59	11.72	1.70	9.03	1.31
$\hat{R}_2$ (20°C)	22.34	3.24	6.76	0.98	2.41	0.35
$\hat{R}_3$ (177°C)	33.30	4.83	-18.41	-2.67	-11.44	-1.66
Columns Exposure Times						
$\hat{C}_1$ (720 hrs)	7.58	1.10	2.07	0.30	12.13	1.76
$\hat{C}_2$ (1440 hrs)	-5.45	-0.79	11.38	1.65	-3.10	-0.45
$\hat{C}_3$ (2400 hrs)	-2.21	-0.32	-13.44	-1.95	-9.03	-1.31
Treatments Environmental Conditions						
$\hat{T}_1$ (177°C)	1.52	0.22	3.03	0.44	-3.93	-0.57
$\hat{T}_2$ (ambient)	2.07	0.30	-1.86	-0.27	1.03	0.15
$\hat{T}_3$ (HA, RH, UV)	-3.59	-0.52	-1.24	-0.18	2.90	0.42

Table VI

Estimate of Environmental Effects on Resin Tensile Modulus

	P-1700 Polysulfone		360 Polyarylsulfone		PR-286 Epoxy	
Mean	2.21 GN/m^2	0.32 msi	2.90 GN/m^2	0.42 msi	3.38 GN/m^2	0.49 msi
Rows Test Temps.						
$\hat{R}_1$ (-55°C)	1.24	0.18	0.55	0.08	2.21	0.32
$\hat{R}_2$ (20°C)	0.97	0.97	0	0	0.83	0.12
$\hat{R}_3$ (177°C)	-2.21	-2.21	0.62	-0.09	-3.03	-0.44
Columns Exposure Times						
$\hat{C}_1$ (720 hrs)	6.93	0.03	0.21	0.03	-0.14	-0.02
$\hat{C}_2$ (1440 hrs)	-0.07	-0.01	0.14	-0.02	0.07	0.01
$\hat{C}_3$ (2400 hrs)	0.14	-0.02	0	0	0.07	0.01
Treatments Environmental Conditions						
$\hat{T}_1$ (177°C)	-0.07	-0.01	0.28	0.04	0.07	0.01
$\hat{T}_2$ (ambient)	0.14	0.02	-0.14	-0.02	-0.07	-0.01
$\hat{T}_3$ (HA, RH, UV)	-0.07	-0.01	-0.14	-0.02	0	0

Table VII

Effect of 177°C Exposure on Resin
Flexural Strength

	0		720 hrs		1440 hrs		2400 hrs	
	MN/m^2	(ksi)	MN/m^2	(ksi)	MN/m^2	(ksi)	MN/m^2	(ksi)
177°C Exposure, -55°C Test Temperature								
P-1700	129.6	18.8	104.66	15.18	105.29	15.27	86.53	12.55
360	160.7	23.3	135.07	19.59	148.38	21.52	154.58	22.42
PR-286	186.9	27.1	92.26	13.38	67.23	9.75	71.29	10.34
177°C Exposure, 20°C Test Temperature								
P-1700	117.2	17.0	109.70	15.91	110.32	16.00	91.63	13.29
360	141.3	20.5	135.56	19.66	148.86	21.59	29.39	22.49
PR-286	134.4	19.5	57.57	8.35	32.48	4.71	39.99	5.80
177°C Exposure, 177°C Test Temperature								
P-1700	0	0	-2.69	-0.39	-2.07	-0.30	-20.75	-3.015
360	63.4	9.2	70.26	10.19	83.57	12.12	89.77	13.02
PR-286	17.9	2.6	-16.27	-2.36	-41.37	-6.00	-33.85	-4.91

Table VIII

Effect of Ambient Exposure on Resin
Flexural Strength

	0		720 hrs		1440 hrs		2400 hrs	
	MN/m^2	(ksi)	MN/m^2	(ksi)	MN/m^2	(ksi)	MN/m^2	(ksi)
AMB Exposure, -55°C Test Temperature								
P-1700	129.6	18.8	120.87	17.53	121.49	17.62	102.74	14.90
360	160.7	23.3	117.84	17.09	131.14	19.02	137.35	19.92
PR-286	186.9	27.1	168.79	24.48	143.76	20.85	151.28	21.94
AMB Exposure, 20°C Test Temperature								
P-1700	117.2	17.0	125.90	18.26	126.52	18.35	107.77	15.63
360	141.3	20.5	118.32	17.16	131.63	19.09	137.83	19.99
PR-286	134.4	19.5	134.11	19.45	109.01	15.81	116.53	16.90
AMB Exposure, 177°C Test Temperature								
P-1700	0	0	13.51	1.96	14.13	2.05	-4.62	-0.67
360	63.4	9.2	53.02	7.69	66.33	9.62	72.53	10.52
PR-286	17.9	2.6	60.26	8.74	35.16	5.10	42.68	6.19

Table IX

Effect of HA, RH, UV Exposure on Resin
Flexural Strength

	0		720 hrs		1440 hrs		2400 hrs	
	MN/m^2	(ksi)	MN/m^2	(ksi)	MN/m^2	(ksi)	MN/m^2	(ksi)
HA, RH, UV Exposure, -55°C Test Temperature								
P-1700	129.6	18.8	116.39	16.88	117.01	16.97	98.32	14.26
360	160.7	23.3	96.94	14.06	110.25	15.99	116.46	16.89
PR-286	186.9	27.1	147.55	21.40	122.52	17.77	130.04	18.86
HA, RH, UV Exposure, 20°C Test Temperature								
P-1700	117.2	17.0	121.42	17.61	122.11	17.71	103.36	14.99
360	141.3	20.5	97.36	14.12	110.73	16.06	116.94	16.96
PR-286	134.4	19.5	112.87	16.37	87.84	12.74	95.36	13.83
HA, RH, UV Exposure, 177°C Test Temperature								
P-1700	0	0	9.03	1.31	9.72	1.41	-9.03	-1.31
360	63.4	9.2	32.13	4.66	45.44	6.59	51.64	7.49
PR-286	17.9	2.6	39.02	5.66	14.00	2.03	21.51	3.12

Table X

Neat Resin Creep/Stress-Rupture Data
177°C Test Temperature

Resin	No.	Stress MN/m^2	Stress ksi	Rupture Time hrs	Environmental Exposure
PR-286	27	2.1	.30	>621	As-fabricated
		3.1	.45	>191	
		3.7	.55	>144	
		4.1	.60	> 96	
		5.2	.75	>119	
		6.2	.90	>122	
		6.9	1.0	> 71	
		8.3	1.2	>119	
		10.3	1.5	>143	
		13.8	2.0	177	
	28	2.1	.30	0	As-fabricated
	29	2.1	.30	>114	1000 hrs @ 177°C
	30	2.1	.30	>167	"
		6.9	1.0	> 94	
		13.8	2.0	0	
	31	2.1	.30	>161	1000 hrs @ ambient
	32	2.1	.30	0	"
	33	2.1	.30	>161	1000 hrs @ RH, HA, UV
	34	2.1	.30	0	"
360	27	9	1.3	0.5	As-fabricated
	28	9	1.3	30	"
	29	9	1.3	65	100 hrs @ 177°C
	30	9	1.3	127	"
	31	9	1.3	81	1000 hrs @ ambient
	32	9	1.3	16	"
	33	9	1.3	14	1000 hrs @ RH, HA, UV
	34	9	1.3	33	"

Table XI

Task II - Test Matrix for Unidirectional Fiber Composites

Property	Exposure Conditions	Exposure Temp. °C			Exposure Time, Hr				Test Temp. °C			
		22	121	177	0	720	1440	2400	-55	22	121	177
Tensile Strength and Modulus	As Fabricated				x				x	x	x	x
Trans. Tensile Strength	Heated Air (HA)		x_1	x_2		BB_{12}	C_1C_2	D_1D_2	$(BCD)_1$ and $(BCD)_2$ at each temp.			
Interlaminar Shear Strength	Ambient[a]	x				E_1	F_1	G_1	$(EFG)_1$ at each temperature			
Flex. Strength and Mod.	HA/RH/UV[b]					H	I	J	HIJ	HIJ	HIJ	HIJ

[a]50% RH

[b]49°C, 95% RH, 61 cm from UV light

Table XII

As-Fabricated T-300 Composite Bending Data
Unidirectional Reinforcement

Matrix	Test Temp. °C	3-Pt. Flexure σ GN/m^2	3-Pt. Flexure σ (ksi)	3-Pt. Flexure E GN/m^2	3-Pt. Flexure E (msi)	Short Beam Shear τ MN/m^2	Short Beam Shear τ (ksi)
PR-286	-55	1.96	284	119	17.3	141	20.4
		1.86	269	118	17.1	151	21.9
	22	1.93	280	142	20.5	120	17.4
		1.74	252	139	20.1	121	17.5
	121	.88	128	125	18.1	81	11.7
		.90	130	116	16.8	68	9.9
	171	.37	53	17	2.5	26	3.8
		.30	43	15	2.2	25	3.7
P-1700	-55	1.19	172	94	13.6	82	11.9
		1.18	171	95	13.8	80	11.6
	22	1.25	181	115	16.7	68	9.9
		1.21	175	130	18.8	65	9.4
	121	.84	121	109	15.8	41	6.0
		.80	116	110	16.0	58	8.4
	177	.10	14	-	-	22	3.2
		.08	11	-	-	21	3.1
360	-55	1.21	175	108	15.7	50	7.3
		.73	106	94	13.7	54	7.8
	22	.72	105	81	11.7	36	5.2
		.80	116	93	13.5	37	5.4
	121	.88	127	99	14.4	38	5.5
		.97	141	112	16.2	41	5.9
	177	.95	138	114	16.5	40	5.8
		.88	128	111	16.1	39	5.6

Table XIII

As-Fabricated T-300 Composite Tensile Data
Unidirectional Reinforcement

Matrix	Test Temp. °C	Transverse Tension σ MN/m^2	Transverse Tension σ (ksi)	Transverse Tension E GN/m^2	Transverse Tension E (msi)	Longitudinal Tension σ GN/m^2	Longitudinal Tension σ (ksi)	Longitudinal Tension E GN/m^2	Longitudinal Tension E (msi)
PR-286	-55	52	7.48	11.2	1.63	1.34	195	142	20.5
		59	8.53	10.8	1.57	1.17	169	135	19.5
	22	71	10.25	10.6	1.54	1.04	151	137	19.9
		44	6.34	10.5	1.52	1.17	170	156	22.6
	121	24	3.46	6.0	0.87	1.26	183	139	20.1
		23	3.31	6.2	0.90	1.14	165	130	18.8
	177	7	1.06	0.9	0.13	.71	103	128	18.6
			0.97	1.0	0.14	.50	73	131	19.2
P-1700	-55	33	4.78	7.7	1.11	1.03	149	129	18.7
		19	2.89	8.7	1.26	1.03	149	134	19.4
	22	28	3.94	8.2	1.19	.96	139	139	20.1
		30	4.30	8.2	1.19	.90	130	143	20.8
	121	14	2.05	7.0	1.01	.90	131	141	20.4
		16	2.31	7.2	1.05	1.05	152	142	20.5
	177	0	0	0	0	.28	40	130	18.8
		0	0	0	0	.23	33	125	18.1
360	-55	21	3.03	8.4	1.22	.90	131	148	21.5
		19	2.78	7.9	1.15	.77	111	144	20.9
	22	21	3.02	7.8	1.13	.82	119	142	20.6
		16	2.35	-	-	.86	125	142	20.6
	121	12	1.74	6.6	0.95	.96	140	141	20.4
		11	1.66	6.8	0.99	1.05	152	157	22.7
	177	8	1.19	5.7	0.82	.83	120	-	-
		8	1.16	5.5	0.79	.90	131	149	21.6

Table XIV

As-Fabricated Cross-Plied Composite Data
Tested at 45°

System	Test Temp. °C	Tension σ MN/m^2	σ (ksi)	E GN/m^2	E (msi)	Unnotched Charpy Energy Joules	Unnotched Charpy Energy (ft-lbs)
T-300/PR-286	22	228	33.1	22.1	3.22	18 1/2	13 1/2
		285	41.3	19.8	2.87	25	18 1/2
	121	81	11.8	9.0	1.31	30	22
		66	9.5	10.0	1.45	21	15 1/2
	177	29	4.2	1.6	0.23		
		21	3.1	0.9	0.14		
T-300/P-1700	22	99	14.3	19.5	2.82	38	28
		112	16.2	18.2	2.63	33	24
	121	59	8.5	14.8	2.15	34 1/2	25 1/2
			11.0	18.5	2.68	33	24
	177	29	4.2	9.3	1.35		
		40	3.9	11.1	1.60		
T-300/360	22	90	13.0	18.9	2.74	23	17
		90	13.0	18.6	2.70	30 1/2	22 1/2
	121	69	10.1	17.3	2.50	23	17
		70	10.2	17.3	2.50	30 1/2	22 1/2
	177	62	9.0	17.3	2.50		
		61	8.8	15.6	2.26		

Table XV

Creep/Stress-Rupture of As-Fabricated Cross-Plied Composites
Tested at 45°

Material	No.	Test Temp. (°C)	Stress MN/m²	Stress (ksi)	Stress % of Static	Rupture Time (hrs)
T-300/P-1700	39	121	52	7.5	75	>113
			59	8 5	85	16 1/2
	47	177	21	3.0	75	0.1
	48	177	14	2.0	50	25
T-300/360	39	121	35	5.1	50	>308
			52	7.6	75	>189
			62	9.0	88	2.3
	47	177	31	4.5	50	>426
			46	6.75	75	>191
			56	8.1	90	1.4
	48	177	31	4.5	50	>240
			46	6.75	75	3.6
T-300/P 286	48	177	19	2.7	75	>113
			22	3.2	89	>132
			24	3.5	97	

Table XVI

Estimate of Environmental Effects on Composite
Interlaminar Shear Strength

	P-1700 Polysulfone Matrix		360 Polysulfone Matrix		PR-286 Epoxy Matrix	
Mean	48.33 MN/m^2	7.01 ksi	43.99 MN/m^2	6.38 ksi	76.67 MN/m^2	11.12 ksi
Rows <u>Test Temps.</u>						
$\hat{R}_1$ (-55°C)	24.75	3.59	5.72	.83	45.92	6.66
$\hat{R}_2$ (20°C)	13.72	1.99	2.69	.39	34.96	5.07
$\hat{R}_3$ (121°C)	-11.58	-1.68	-1.17	-.17	-28.89	-4.19
$\hat{R}_4$ (177°C)	-26.89	-3.90	-7.24	-1.05	-51.99	-7.54
Columns <u>Exposure Times</u>						
$\hat{C}_1$ (720 hrs)	1.65	.24	1.17	.17	8.27	1.20
$\hat{C}_2$ (1000 hrs)	8.69	1.26	-4.48	-.65	-0.28	-.04
$\hat{C}_3$ (1440 hrs)	-5.17	-.75	3.72	.54	4.90	.71
$\hat{C}_4$ (2400 hrs)	-5.24	-.76	-0.41	-.06	-12.89	-1.87
Treatments <u>Environments</u>						
$\hat{T}_1$ (177°C)	-11.93	-1.73	-0.028	-.004	-12.89	-1.87
$\hat{T}_2$ (121°C)	0.76	.11	2.69	.39	11.51	1.67
$\hat{T}_3$ (ambient)	7.79	1.13	1.48	.21	5.52	.80
$\hat{T}_4$ (HA,RH,UV)	3.24	.47	-4.14	-.60	4.14	-.60

Table XVII

Estimate of Environmental Effects on Composite Transverse Tensile Strength

	P-1700 Polysulfone Matrix		360 Polysulfone Matrix		PR-286 Epoxy Matrix	
Mean	13.58 MN/m^2	1.97 ksi	13.86 MN/m^2	2.01 ksi	24.82 MN/m^2	3.60 ksi
Rows						
Test Temps.						
$\hat{R}_1$ (-55°C)	8.00	1.16	8.69	1.26	8.27	1.20
$\hat{R}_2$ (20°C)	8.41	1.22	-0.28	-0.04	17.86	2.59
$\hat{R}_3$ (121°C)	-3.93	-0.57	-1.86	-0.27	-5.38	-0.78
$\hat{R}_4$ (177°C)	-12.55	-1.82	-6.48	-0.94	-20.75	-3.01
Columns						
Exposure Times						
$\hat{C}_1$ (720 hrs)	-1.38	-0.20	-1.86	-0.27	-2.41	-0.35
$\hat{C}_2$ (1000 hrs)	2.83	0.41	-2.28	-0.33	8.27	1.20
$\hat{C}_3$ (1440 hrs)	-6.92	-0.03	7.58	1.10	-4.55	-0.66
$\hat{C}_4$ (2400 hrs)	-7.07	-0.17	-3.38	-0.49	-1.17	-0.17
Treatments						
Environments						
$\hat{T}_1$ (177°C)	-6.62	-0.96	-4.27	-0.62	-1.72	-0.25
$\hat{T}_2$ (121°C)	1.52	0.22	7.10	1.03	1.31	0.19
$\hat{T}_3$ (ambient)	0.76	0.11	-1.10	-0.16	5.72	0.83
$\hat{T}_4$ (HA,RH,UV)	4.27	0.62	-1.59	-0.23	-5.38	-0.78

Table XVIII

Estimate of Environmental Effects on Composite
Transverse Tensile Modulus

	P-1700 Polysulfone Matrix		360 Polysulfone Matrix		PR-286 Epoxy Matrix	
Mean	4.69 GN/m^2	0.68 msi	6.34 GN/m^2	0.92 msi	6.14 GN/m^2	0.89 msi
Rows Test Temps.						
$\hat{R}_1$ (-55°C)	2.55	0.37	1.72	0.25	4.27	0.62
$\hat{R}_2$ (20°C)	2.76	0.40	-0.48	-0.07	2.96	0.43
$\hat{R}_3$ (121°C)	-0.90	-0.13	-2.07	-0.30	-1.79	-0.26
$\hat{R}_4$ (171°C)	-4.34	-0.63	0.83	0.12	-5.44	-0.79
Columns Exposure Times						
$\hat{C}_1$ (720 hrs)	0.34	0.05	-0.97	-0.14	0.07	0.01
$\hat{C}_2$ (1000 hrs)	1.17	0.17	1.10	0.16	0.21	0.03
$\hat{C}_3$ (1440 hrs)	-1.45	-0.21	0.41	0.06	0.41	-0.06
$\hat{C}_4$ (2400 hrs)	-0.07	-0.01	-2.55	-0.37	0.07	0.01
Treatments Environments						
$\hat{T}_1$ (177°C)	-1.86	-0.27	-2.07	-0.30	0.41	0.06
$\hat{T}_2$ (121°C)	-0.41	-0.06	1.38	0.20	0.07	0.01
$\hat{T}_3$ (ambient)	1.10	0.16	1.24	0.18	0.21	0.03
$\hat{T}_4$ (HA,RH,UV)	1.17	0.17	-0.55	-0.08	-0.76	-0.11

Table XIX

Estimate of Environmental Effects on Composite
Longitudinal Tensile Strength

	P-1700 Polysulfone Matrix		360 Polysulfone Matrix		PR-286 Epoxy Matrix	
Mean	825.68 MN/m^2	119.75 ksi	870.91 MN/m^2	126.3 ksi	890.97 MN/m^2	129.22 ksi
Rows Test Temps.						
$\hat{R}_1$ (-55°C)	198.23	28.75	141.55	20.53	199.82	28.98
$\hat{R}_2$ (20°C)	-36.68	-5.32	-28.50	-4.13	157.07	22.78
$\hat{R}_3$ (121°C)	65.85	9.55	-27.30	-3.96	-45.78	-6.64
$\hat{R}_4$ (177°C)	-227.33	-32.97	-85.70	-12.43	311.03	-45.11
Columns Exposure Times						
$\hat{C}_1$ (720 hrs)	-82.74	-12.00	168.44	24.43	-95.77	-13.89
$\hat{C}_2$ (1000 hrs)	149.97	21.75	133.97	19.43	146.73	21.28
$\hat{C}_3$ (1440 hrs)	83.43	12.10	-128.11	-18.58	-39.03	-5.66
$\hat{C}_4$ (2400 hrs)	-150.59	-21.84	-173.16	-25.18	-11.79	-1.71
Treatments Environments						
$\hat{T}_1$ (177°C)	15.38	2.23	228.98	33.21	96.05	13.93
$\hat{T}_2$ (121°C)	-135.62	-19.67	-138.59	-20.41	-159.90	-23.19
$\hat{T}_3$ (ambient)	105.15	15.25	-158.10	-22.93	109.84	15.93
$\hat{T}_4$ (HA,RH,UV)	15.17	2.20	69.85	10.13	-45.92	-6.66

Table XX

Estimate of Environmental Effects on Composite Longitudinal Tensile Modulus

	P-1700 Polysulfone Matrix		360 Polysulfone Matrix		PR-286 Epoxy Matrix	
Mean	124.04 GN/m^2	17.99 msi	135.76 GN/m^2	19.69 msi	119.70 GN/m^2	17.36 msi
Rows Test Temps.						
$\hat{R}_1$ (-55°C)	-3.17	-0.46	-5.45	-0.79	1.93	0.28
$\hat{R}_2$ (20°C)	0.21	0.03	5.38	0.78	1.45	0.21
$\hat{R}_3$ (121°C)	12.27	1.78	0.83	0.12	6.41	0.93
$\hat{R}_4$ (177°C)	-9.38	-1.36	-0.76	-0.11	-8.96	-1.43
Columns Exposure Times						
$\hat{C}_1$ (720 hrs)	-15.24	-2.21	5.31	0.77	-14.69	-2.13
$\hat{C}_2$ (1000 hrs)	2.96	0.43	-0.69	-0.41	3.17	0.46
$\hat{C}_3$ (1440 hrs)	20.89	3.03	2.07	0.43	3.17	0.46
$\hat{C}_4$ (2400 hrs)	-.869	-.126	-5.45	-0.79	8.34	1.21
Treatments Environments						
$\hat{T}_1$ (177°C)	-25.24	-3.66	0.90	0.13	18.82	2.73
$\hat{T}_2$ (121°C)	18.48	2.68	-4.90	-0.71	-9.72	-1.41
$\hat{T}_3$ (ambient)	7.10	1.03	-1.24	-0.18	1.93	0.28
$\hat{T}_4$ (HA,RH,UV)	-0.41	-0.06	5.24	0.76	-11.10	-1.61

Table XXI

Estimate of Environmental Effects on Composite Flexural Strength

	P-1700 Polysulfone Matrix		360 Polysulfone Matrix		PR-286 Epoxy Matrix	
Mean	773.76 MN/m^2	112.22 ksi	943.58 MN/m^2	136.85 ksi	1200.90 MN/m^2	174.17 ksi
Rows						
Test Temps.						
$\hat{R}_1$ (-55°C)	88.12	12.78	48.95	7.10	209.95	30.45
$\hat{R}_2$ (20°C)	409.08	59.33	189.61	27.50	631.17	91.54
$\hat{R}_3$ (121°C)	194.78	28.25	80.33	11.65	33.23	4.82
$\hat{R}_4$ (177°C)	-691.98	-100.36	-318.82	-46.24	874.42	-126.82
Columns						
Exposure Times						
$\hat{C}_1$ (720 hrs)	-145.21	-21.06	-277.32	-40.22	-242.84	-35.22
$\hat{C}_2$ (1000 hrs)	121.01	17.55	82.19	11.92	67.71	9.82
$\hat{C}_3$ (1440 hrs)	137.21	19.90	151.00	21.90	53.92	7.82
$\hat{C}_4$ (2400 hrs)	113.01	-16.39	44.13	6.40	121.15	17.57
Treatments						
Environments						
$\hat{T}_1$ (177°C)	-245.46	-35.46	56.81	8.42	83.08	12.05
$\hat{T}_2$ (121°C)	224.78	32.60	-115.84	-16.84	-146.17	-21.20
$\hat{T}_3$ (ambient)	55.71	8.08	60.33	8.75	-9.79	-1.42
$\hat{T}_4$ (HA,RH,UV)	-35.92	-5.21	-2.21	-0.32	72.88	10.57

Table XXII

Estimate of Environmental Effects on Composite
Flexural Modulus

	P-1700 Polysulfone Matrix		360 Polysulfone Matrix		PR-286 Epoxy Matrix	
Mean	76.46 GN/m^2	11.09 msi	104.18 GN/m^2	15.11 msi	106.87 GN/m^2	15.50 msi
Rows **Test Temps.**						
$\hat{R}_1$ (-55°C)	-.97	-0.14	-6.00	-0.87	10.68	-1.55
$\hat{R}_2$ (20°C)	31.58	4.58	8.20	1.19	25.86	3.75
$\hat{R}_3$ (121°C)	106.46	15.44	12.34	1.79	22.20	3.22
$\hat{R}_4$ (177°C)	15.79	2.29	-14.48	-2.10	-37.37	-5.42
Columns **Exposure Times**						
$\hat{C}_1$ (720 hrs)	-17.37	-2.52	-27.51	-3.99	-22.40	-3.27
$\hat{C}_2$ (1000 hrs)	12.41	1.80	6.96	1.01	11.86	1.72
$\hat{C}_3$ (1440 hrs)	-.76	-0.11	-1.93	-0.28	-10.83	-1.57
$\hat{C}_4$ (2400 hrs)	5.72	0.83	22.48	3.26	21.51	3.12
Treatments **Environments**						
$\hat{T}_1$ (177°C)	-23.44	-3.40	6.14	0.89	17.58	2.55
$\hat{T}_2$ (121°C)	16.55	2.40	-18.49	-2.70	-11.03	-1.60
$\hat{T}_3$ (ambient)	5.03	0.73	7.17	1.04	-13.38	-1.94
$\hat{T}_4$ (HA,RH,UV)	1.72	0.25	5.31	0.77	6.89	1.00

Table XXIII

Effect of 177°C Exposure on Composite
Shear Strength

Matrix	0		720 hrs		240 hrs		1440 hrs		2400 hrs	
	MN/m^2	(ksi)	MN/m^2	(ksi)	MN/m^2	(ksi)	MN/m^2	(ksi)	MN/m^2	(ksi)
177°C Exposure, -55°C Test Temp.										
P-1700	81.4	11.8	62.81	9.11	69.85	10.13	55.99	8.12	55.92	8.11
360	52.4	7.6	50.88	7.38	45.23	6.56	53.44	7.75	49.30	7.15
PR-286	145.5	21.1	117.97	17.11	109.42	15.87	114.59	16.62	96.81	14.04
177°C Exposure, 20°C Test Temp.										
P-1700	66.2	9.6	51.78	7.51	58.81	8.53	44.96	6.52	44.89	6.51
360	36.5	5.3	47.85	6.94	42.12	6.12	50.40	7.31	46.26	6.71
PR-286	220.0	17.4	107.01	15.52	98.46	14.28	103.63	15.03	85.84	12.45
177°C Exposure, 121°C Test Temp.										
P-1700	49.6	7.2	26.48	3.84	33.51	4.86	19.65	2.85	19.58	2.84
360	39.3	5.7	43.99	6.38	38.34	5.56	46.54	6.75	42.40	6.15
PR-286	74.5	10.8	43.16	6.26	34.61	5.02	39.78	5.77	21.99	3.19
177°C Exposure, 177°C Test Temp.										
P-1700	22.1	3.2	11.17	1.62	18.20	2.64	4.34	.63	4.27	.62
360	39.3	5.7	37.92	5.50	32.27	4.68	40.47	5.87	36.34	5.27
PR-286	26.2	3.8	20.06	2.91	11.51	1.67	16.69	2.42	7.65	1.11

Table XXIV

Summary of Environmental Effects on
Composite Longitudinal Tensile Modulus

Exposure	Matrix	Test Temperatures -55°C	20°C	121°C	177°C
Ambient	286	N/E	Slight drop	N/E	Slight drop
	1700	N/E	Slight drop	N/E	Slight drop
	360	N/E	N/E	Slight drop	Slight drop
RH,HA,UV	286	Drop to 60%	Drop to ~70%	Slight drop	Drop to 75%
	1700	Slight drop	Slight drop	Slight drop	Drop to 85%
	360	Slight drop	N/E	N/E	N/E
177°C	286	N/E	N/E	Slight increase	N/E
	1700	Drop to 70%	Drop to 65%	Drop to 75%	Drop to 65%
	360	Slight drop	N/E	N/E	N/E
121°C	286	Slight drop	Slight drop	N/E	Slight drop
	1700	N/E	N/E	Increase	N/E
	360	Slight drop	N/E	Slight drop	Slight drop

N/E = No Effect

Table XXV

Summary of Environmental Effects on
Composite Flex Modulus

		Test Temperatures			
Exposure	Matrix	-55°C	20°C	121°C	177°C
Ambient	286	N/E	N/E	Slight increase	Increase
	1700	N/E	N/E	Slight increase	N/E
	360	Slight increase	Increase	Increase	N/E
RH,HA,UV	286	N/E	N/E	Increase	Increase
	1700	Slight drop	N/E	N/E	~0
	360	Slight increase	Increase	Increase	N/E
177°C	286	Slight increase	Slight increase	Increase	Increase
	1700	Drop to 60%	Slight drop	Drop to 60%	~0
	360	Increase	Increase	Increase	N/E
121°C	286	Slight drop	N/E	Slight increase	Increase
	1700	N/E	N/E	Slight increase	Increase
	360	N/E	Slight increase	N/E	Slight drop

N/E = No Effect

Table XXVI

Summary of Environmental Effects on Composite Shear Strength

Exposure	Matrix	Test Temperatures -55°C	20°C	121°C	177°C
Ambient	286	Drop to 80%	Slight decrease	Drop to 55%	Slight decrease
	1700	N/E	N/E	Slight decrease	N/E
	360	N/E	Slight increase	N/E	N/E
RH,HA,UV	286	Drop to 75%	Slight drop	Drop to 45%	Drop to 25%
	1700	N/E	N/E	Slight drop	Slight drop
	360	N/E	N/E	N/E	Slight drop
177°C	286	Drop to 65%	Drop to 75%	Drop to 30%	Drop to 0
	1700	Drop to 65%	Drop to 70%	Drop to 45%	Drop to ~ 0
	360	N/E	Slight increase	N/E	Slight decrease
121°C	286	Slight drop	N/E	Drop to 65%	N/E*
	1700	N/E	N/E	Drop to 65%	N/E*
	360	N/E	N/E	Slight increase	N/E

N/E = No Effect

*0 exposure value appeared low

Table XXVII

Summary of Environmental Effects on
Composite Transverse Tensile Strength

Exposure	Matrix	Test Temperatures -55°C	20°C	121°C	177°C
Ambient	286	Drop to 70%	N/E	N/E	N/E
	1700	N/E	N/E	N/E	0
	360	N/E	N/E	N/E	N/E
RH,HA,UV	286	Drop to 50%	Slight Drop	Drop to 65%	Drop to 0
	1700	N/E	N/E	N/E	~0
	360	N/E	Slight Drop	Slight Drop	Slight Drop
177°C	286	Drop to 60%	N/E	Slight Drop	Drop to 0
	1700	Drop to 60%	Drop to 60%	~0	0
	360	Slight Drop	Drop to 60%	Slight Drop	Drop to ~0
121°C	286	Drop to 60%	N/E	N/E	N/E
	1700	Slight Drop	N/E	Slight Drop	0
	360	N/E	N/E	N/E	Increase

N/E = No Effect

Table XXVIII

Summary of Environmental Effects on
Composite Longitudinal Tensile Strength

Exposure	Matrix	Test Temperatures -55°C	20°C	121°C	177°C
Ambient	286	N/E	N/E	Slight Decrease	N/E
	1700	N/E	Slight Decrease	Slight Decrease	Increase
	360	Slight Decrease	Drop to 65%	Drop to 65%	Drop to 60%
RH,HA,UV	286	Slight Decrease	N/E	Drop to 70%	N/E
	1700	N/E	Slight Decrease	Slight Decrease	Slight Increase
	360	N/E	N/E	Drop to 75%	Slight Decrease
177°C	286	N/E	N/E	Drop to 80%	N/E
	1700	N/E	Drop to 80%	Drop to 80%	Increase
	360	Increase	N/E	Slight Decrease	N/E
121°C	286	N/E	N/E	Slight Decrease	N/E
	1700	Drop to 60%	Drop to 60%	Drop to 65%	N/E (~0)
	360	Increase	N/E	N/E	N/E

N/E = No Effect

Table XXIX

Summary of Environmental Effects on Composite Flex Strength

		Test Temperatures			
Exposure	Matrix	-55°C	20°C	121°C	177°C
Ambient	286	Slight Decrease (85%)	N/E	Increase	N/E
	1700	Slight Decrease	N/E	Slight Increase	0 Strength
	360	N/E	Increase	Increase	Slight Decrease
RH,HA,UV	286	Slight Decrease	Slight Increase	Increase	Slight Increase
	1700	Drop to 60%	Drop to 70%	N/E	0 Strength
	360	N/E	Increase	Increase	Slight Decrease
177°C	286	Slight Decrease	Slight Increase	Increase	Slight Increase
	1700	Drop to 45%	Drop to 70%	Slight Decrease	0 Strength
	360	N/E	Increase	Slight Increase	Slight Decrease
121°C	286	Slight Decrease	N/E	Increase	N/E
	1700	Slight Decrease	N/E	Increase	N/E
	360	N/E	Increase	N/E	Slight Decrease

N/E = No Effect

Table XXX

Summary of Environmental Effects on Composite
Composite Transverse Tensile Modulus

Exposure	Matrix	Test Temperatures -55°C	20°C	121°C	177°C
Ambient	286	N/E	N/E	N/E	~0
	1700	N/E	N/E	Slight Drop	~0
	360	N/E	Drop to 60%	Drop to ~50%	N/E
RH,HA,UV	286	Slight drop	N/E	Drop to 65%	N/E (~0)
	1700	N/E	N/E	Drop to 75%	N/E (~0)
	360	Drop to 65%	Drop to 35%	Drop to 20%	Slight drop
177°C	286	N/E	N/E	Slight drop	N/E (~0)
	1700	Slight drop	Slight drop	Drop to 25%	0 mod.
	360	Drop to 50%	Drop to 20%	Drop to 0	Drop to 50%
121°C	286	N/E	N/E	Slight drop	~0
	1700	N/E	N/E	Drop to 50%	0 mod.
	360	N/E	Drop to 60%	Drop to 50%	N/E

Data reflect resin modulus results assuming 2400 hr. effect on 360 composites is incorrect.

N/E = No Effect

Table XXXI

Effect of 121°C Aging Plus Thermal Cycling[a] on Cross-Plied Composite Tensile Properties Tested at 45°

Matrix	Test Temp.	Tensile Strength		Tensile Modulus	
	°C	MN/m^2	ksi	GN/m^2	msi
PR-286	20	220	31.8	14.4	2.09
		188	27.3	21.0	3.04
	121	119	17.2	11.1	1.60
		88	12.7	7.6	1.10
P-1700	20	86	12.5	10.5	1.52
360	20	76	11.1	15.5	2.25
		63	9.2	14.6	2.12
	121	44	6.4	9.7	1.41
		50	7.3	11.0	1.59

[a]Specimens aged 1000 hrs. @ 121°C then cycled 1000 times between -55°C and 177°C

Table XXXII

PR-286 Composite Stress-Rupture Results

No.	Test Temp.	Stress		Rupture Time	Environmental Exposure
	°C	MN/m^2	ksi	hrs	
39	121	60	8.7	> 89.1	As-Fabricated
40		62	9.0	>281	As-Fabricated
		69	10.0	33	
41		62	9.0	0	1000 hrs @ 177°C
42		62	9.0	>208	1000 hrs @ 177°C
43		60	8.7	0.1	1000 hrs @ RH,HA,UV
44		62	9.0	0	1000 hrs @ RH,HA,UV
45		60	8.7	>114	1000 hrs @ ambient
46		62	9.0	>328	1000 hrs @ ambient
		69	10.0	>256	
47	177	14	2.0	>137	As-Fabricated
48		19	2.7	>115	As-Fabricated
		22	3.2	>143	
		24	3.5	> 96	
		26	3.7	>143	
		28	4.0	>169	
		30	4.3	>198	
		31	4.5	>271	
		35	5.0	> 65	
		38	5.5	> 72	
		41	6.0	> 96	
		45	6.5	41	
49		14	2.0	0.3	1000 hrs @ 177°C
50		45	6.5	0	1000 hrs @ 177°C
51		14	2.0	>140	1000 hrs @ RH,HA,UV
52		45	6.5	0	1000 hrs @ RH,HA,UV
53		14	2.0	>162	1000 hrs @ ambient
54		14	2.0	>208	1000 hrs @ ambient

Table XXXIII

P-1700 Composite Stress-Rupture Results

No.	Test Temp.	Stress		Rupture Time	Environmental Exposure
	°C	MN/m^2	ksi	hrs	
39	121	52	7.5	>114	As-Fabricated
		59	8.5	16	
40		59	8.5	0.2	As-Fabricated
41		59	8.5	0	1000 hrs @ 177°C
42		59	8.5	0	1000 hrs @ 177°C
43		59	8.5	128	1000 hrs @ RH,HA,UV
44		59	8.5	>185	1000 hrs @ RH,HA,UV
45		59	8.5	0.4	1000 hrs @ ambient
46		59	8.5	45	1000 hrs @ ambient
47	177	21	3.0	0.1	As-Fabricated
48		14	2.0	25.2	As-Fabricated
49		14	2.0	3.8	1000 hrs @ 177°C
50		14	2.0	0.9	1000 hrs @ 177°C
51		14	2.0	2.7	1000 hrs @ RH,HA,UV
52		14	2.0	5	1000 hrs @ RH,HA,UV
53		14	2.0	4.2	1000 hrs @ ambient
54		14	2.0	0.3	1000 hrs @ ambient

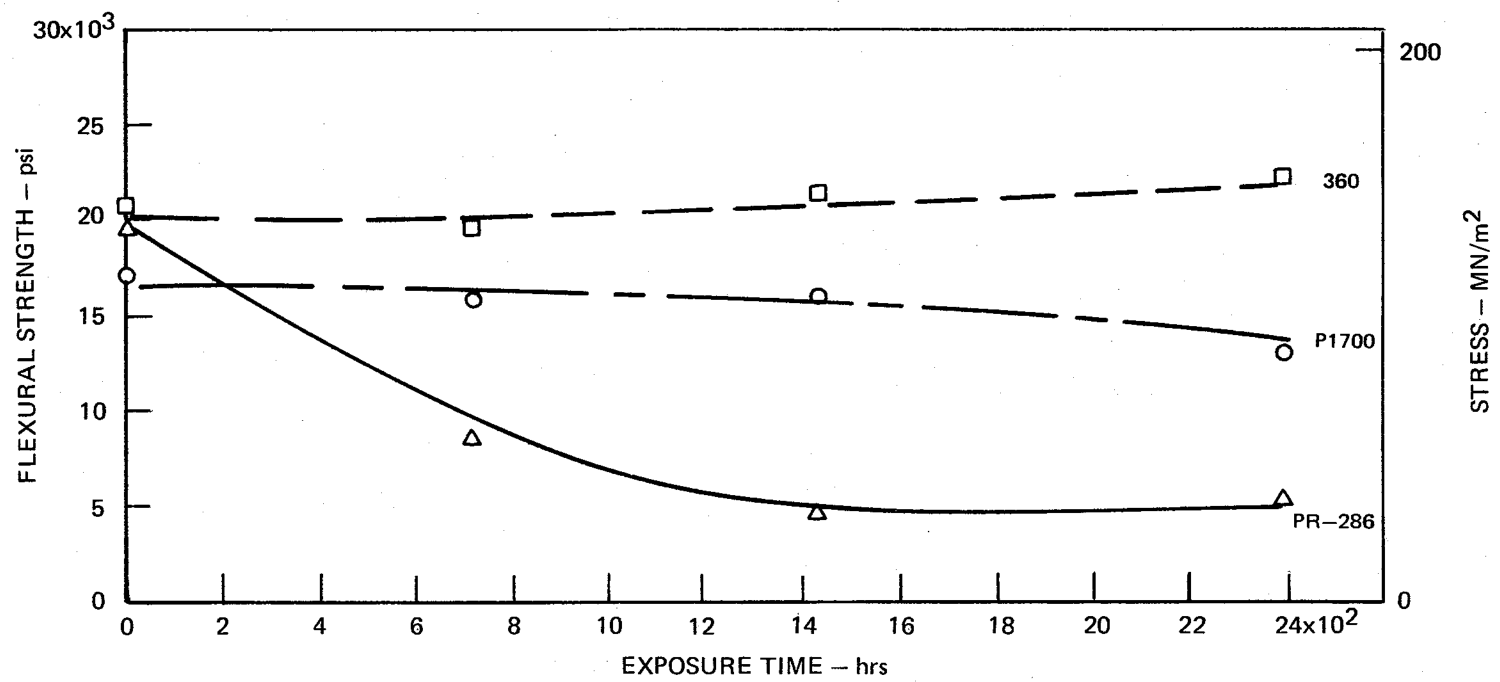
Table XXXIV

360 Composite Stress-Rupture Results

No.	Test Temp.	Stress		Rupture Time	Environmental Exposure
	°C	MN/m^2	ksi	hrs	
39	121	36	5.1	>308	As-Fabricated
		52	7.6	>189	
		62	9.0	2	
40		62	9.0	0	As-Fabricated
41		62	9.0	0	1000 hrs @ 177°C
42		62	9.0	0.3	1000 hrs @ 177°C
43		52	7.6	6.2	1000 hrs @ RH,HA,UV
44		62	9.0	1.4	1000 hrs @ RH,HA,UV
45		52	7.6	48	1000 hrs @ ambient
46		62	9.0	8.3	1000 hrs @ ambient
47	177	31	4.5	>426	As-Fabricated
		46	6.7	>191	
		56	8.1	1.4	
48		31	4.5	>240	As-Fabricated
		46	6.7	3.6	
49		46	6.7	> 65	1000 hrs @ 177°C
50		46	6.7	0	1000 hrs @ 177°C
51		46	6.7	1.7	1000 hrs @ RH,HA,UV
52		46	6.7	3.6	1000 hrs @ RH,HA,UV
53		46	6.7	4.0	1000 hrs @ ambient
54		46	6.7	0.7	1000 hrs @ ambient

FIG. 1

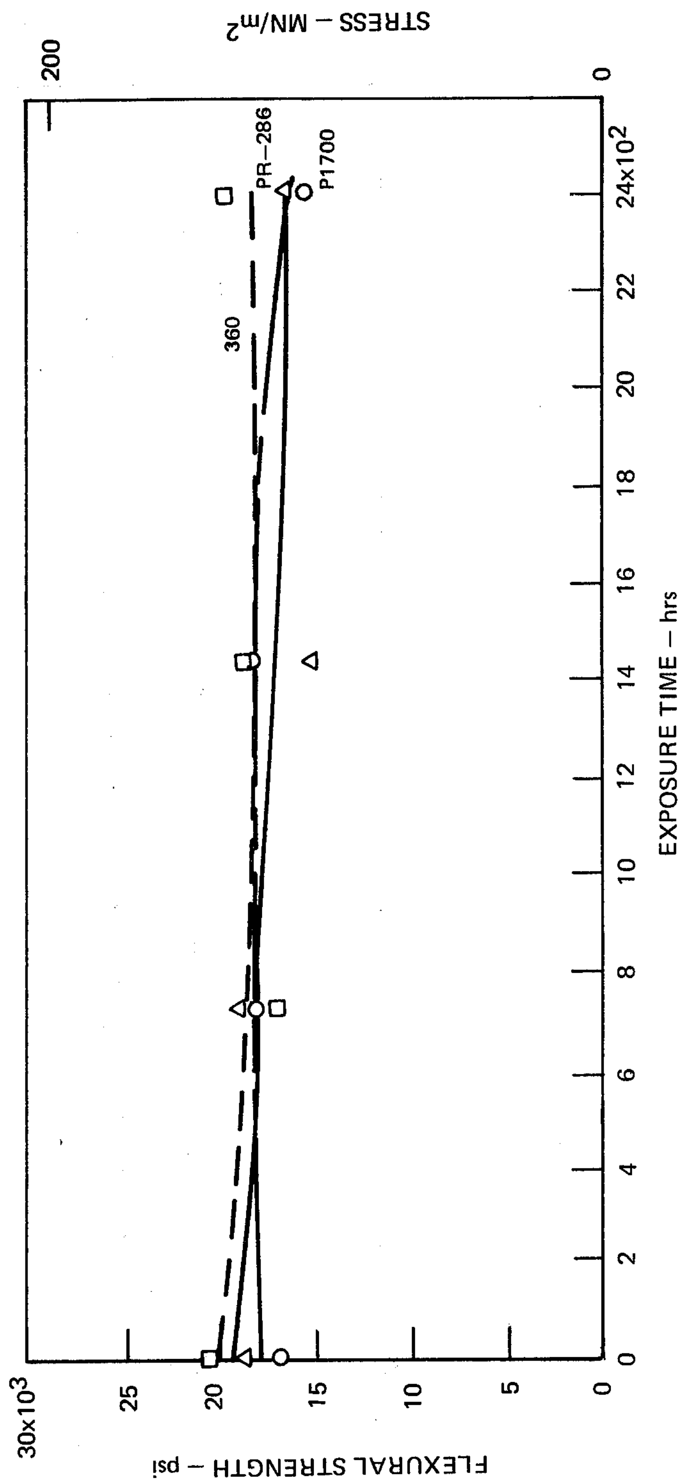
EFFECT OF 177°C EXPOSURE ON 20°C RESIN FLEXURAL STRENGTH



R07–32–1

FIG. 2

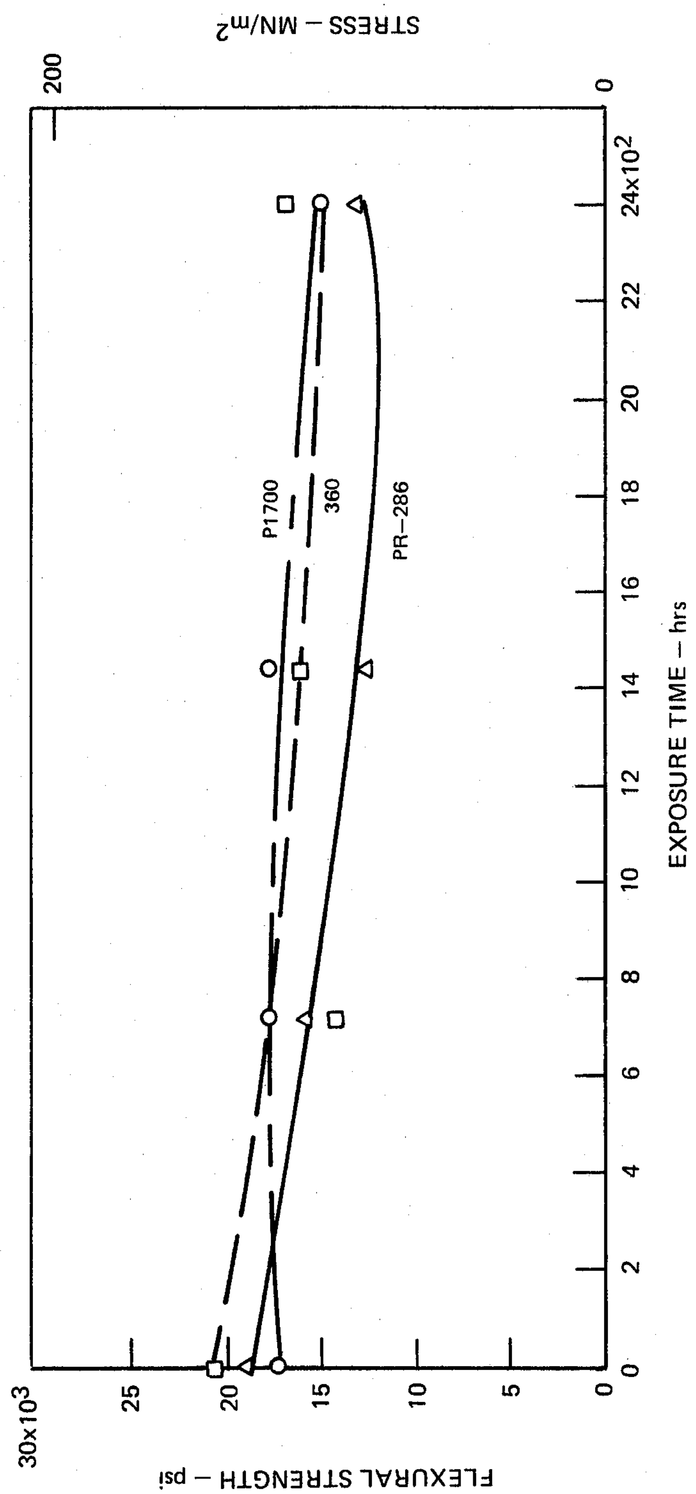
EFFECT OF AMBIENT EXPOSURE ON 20°C RESIN FLEXURAL STRENGTH



R07–32–2

FIG. 3

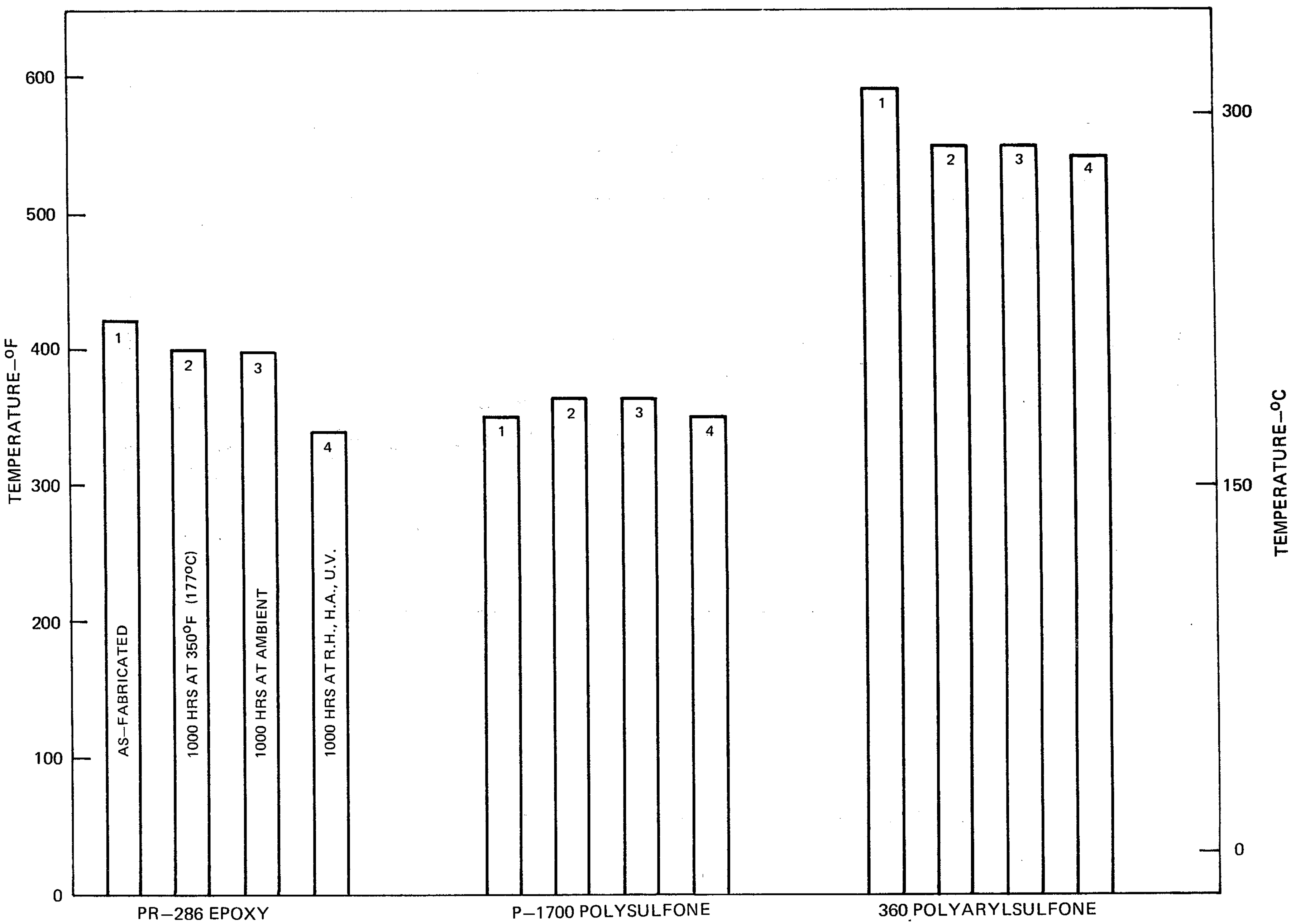
EFFECT OF HA, RH, UV EXPOSURE ON 20°C RESIN FLEXURAL STRENGTH



R07–32–3

FIG. 4

EFFECT OF ENVIRONMENT ON RESIN GLASS TRANSITION TEMPERATURE



R06—234—2

CREEP OF PR–286 AT 177°C, 2.1 MN/m² (0.3 ksi)

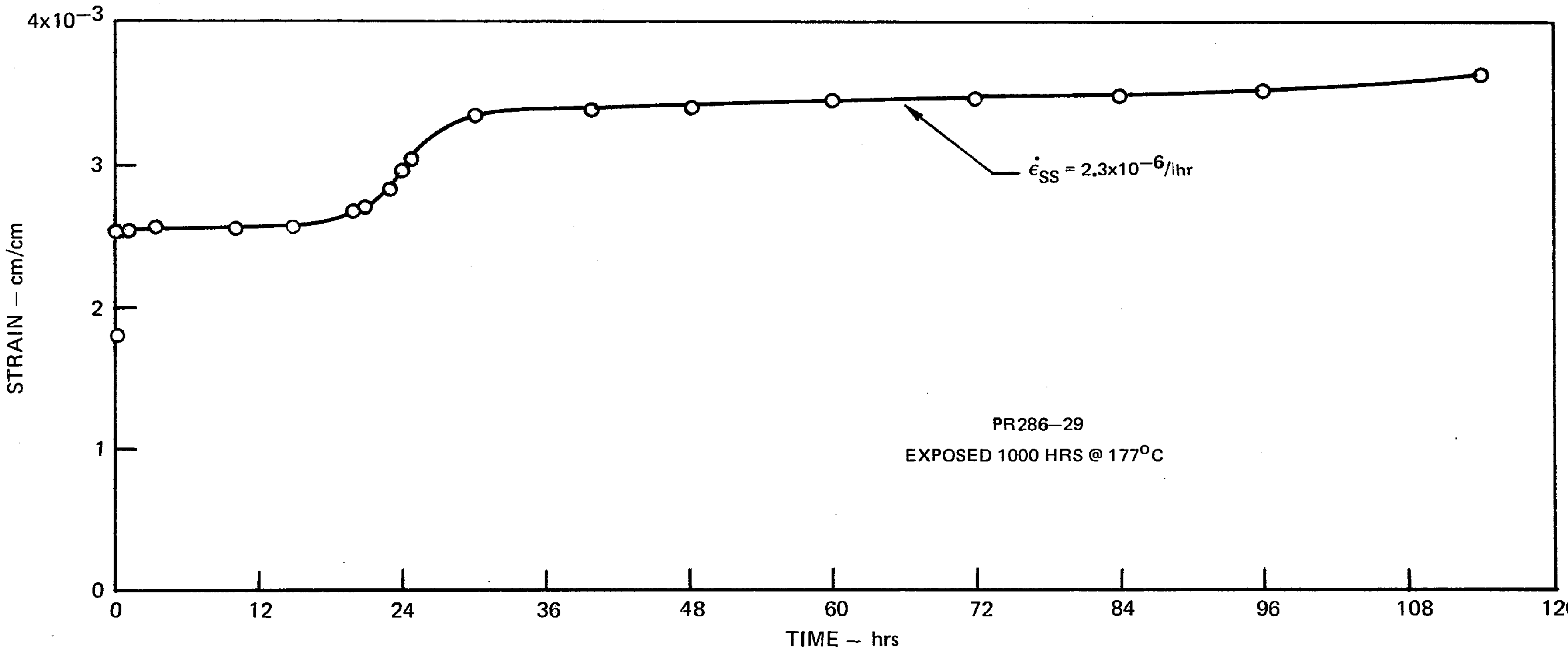


FIG. 5

R07–127–2

CREEP OF 360 AT 177°C, 9 MN/m² (1.3 ksi)

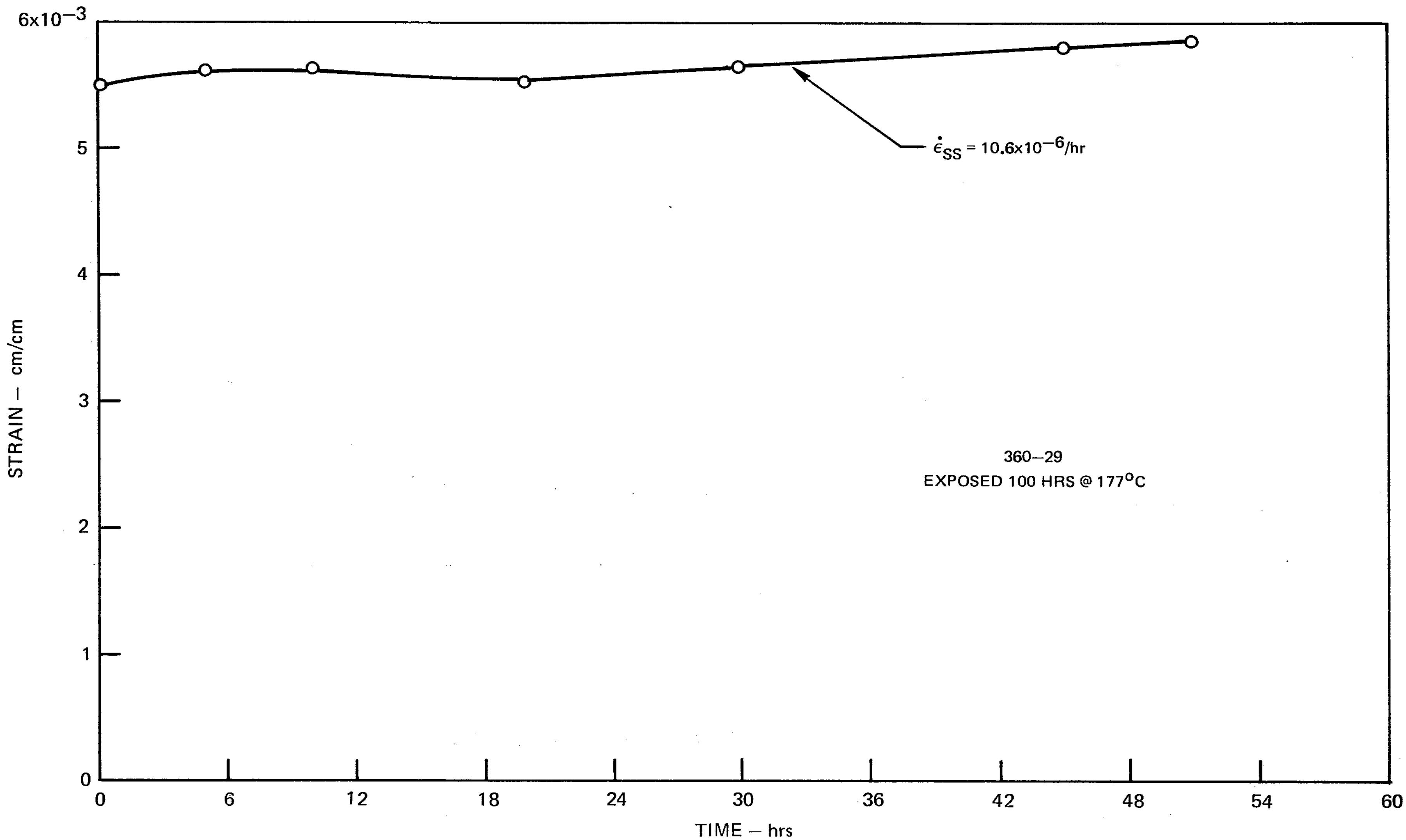


FIG. 6

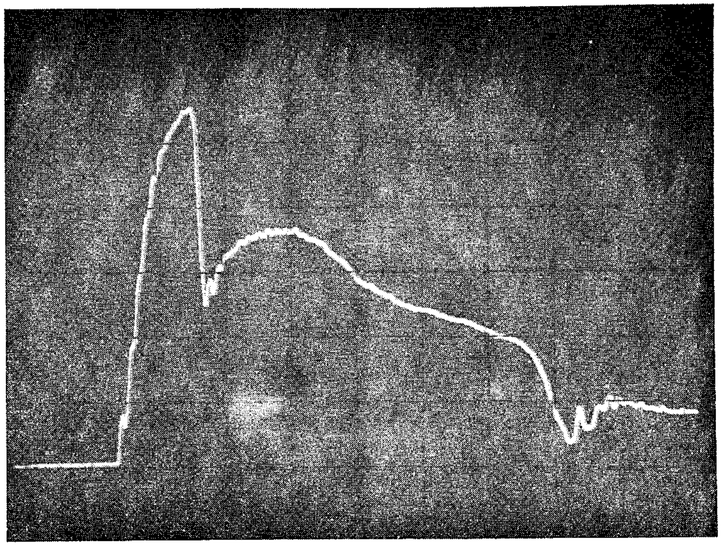
R07–127–5

INSTRUMENTED PENDULUM IMPACT LOAD–TIME CURVES

T–300 CROSS–PLIED COMPOSITES TESTED AT $\pm 45^{\circ}$

R.T. TESTS

P–1700 MATRIX



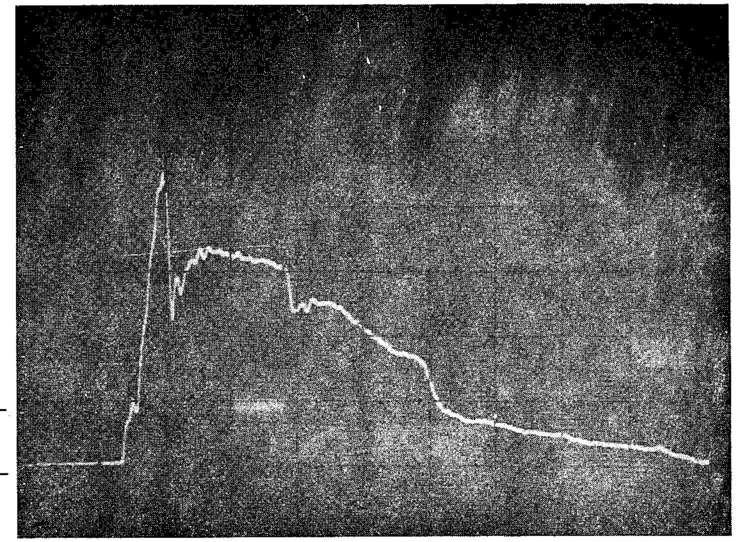
LOAD (N)

710

500

TIME (μ – SECS)

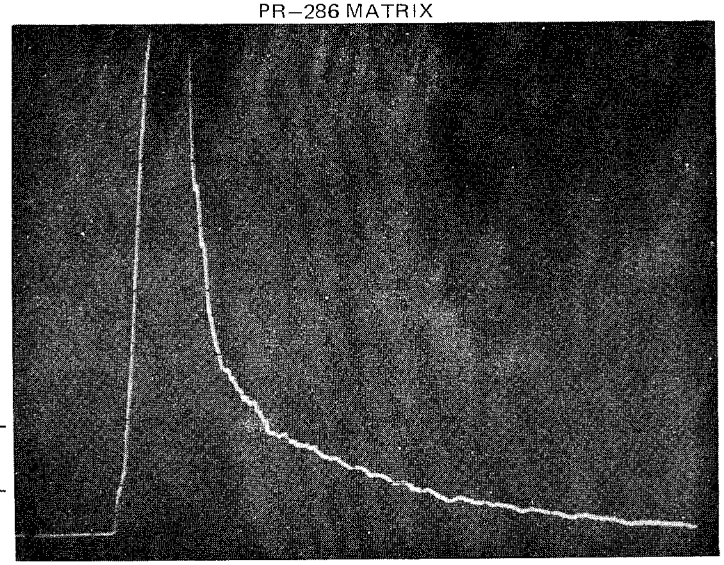
360 MATRIX



710

500

PR–286 MATRIX



710

500

FIG. 7

R07–85–2

INSTRUMENTED PENDULUM IMPACT LOAD–TIME CURVES

T–300 CROSS–PLIED COMPOSITES TESTED AT $\pm 45^{o}$

$121^{o}C$ TESTS

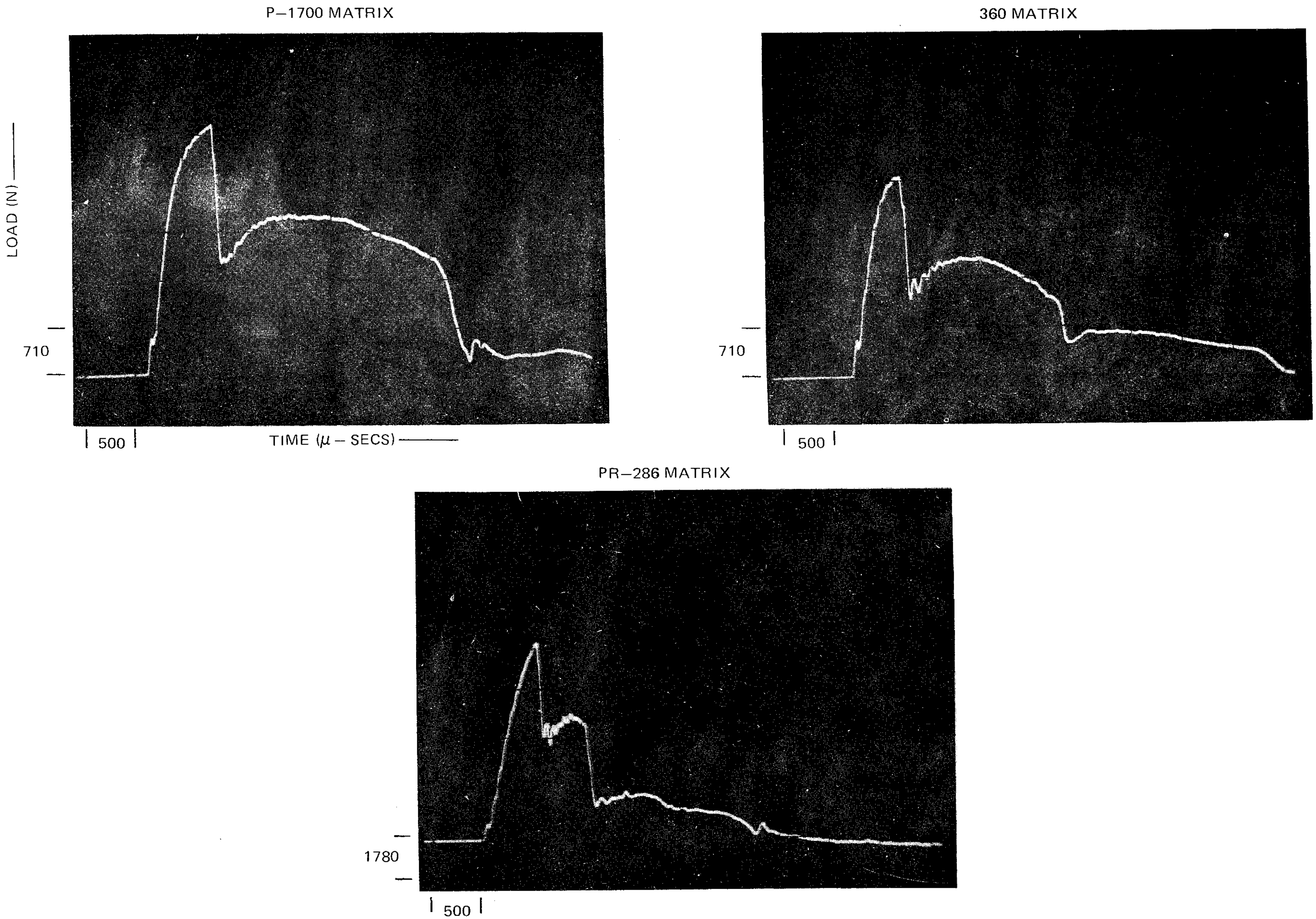
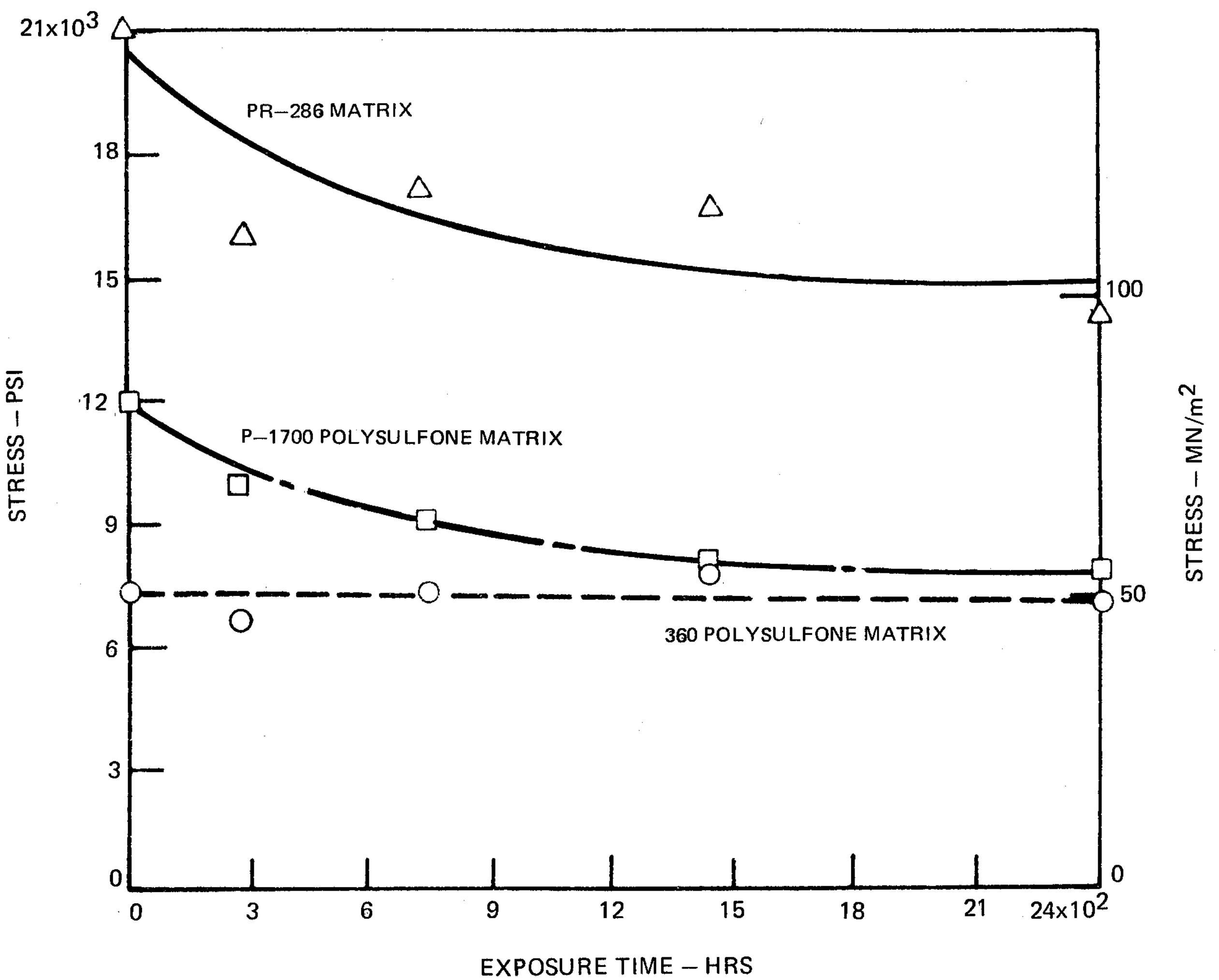


FIG. 8

R07–85–1

FIG. 9

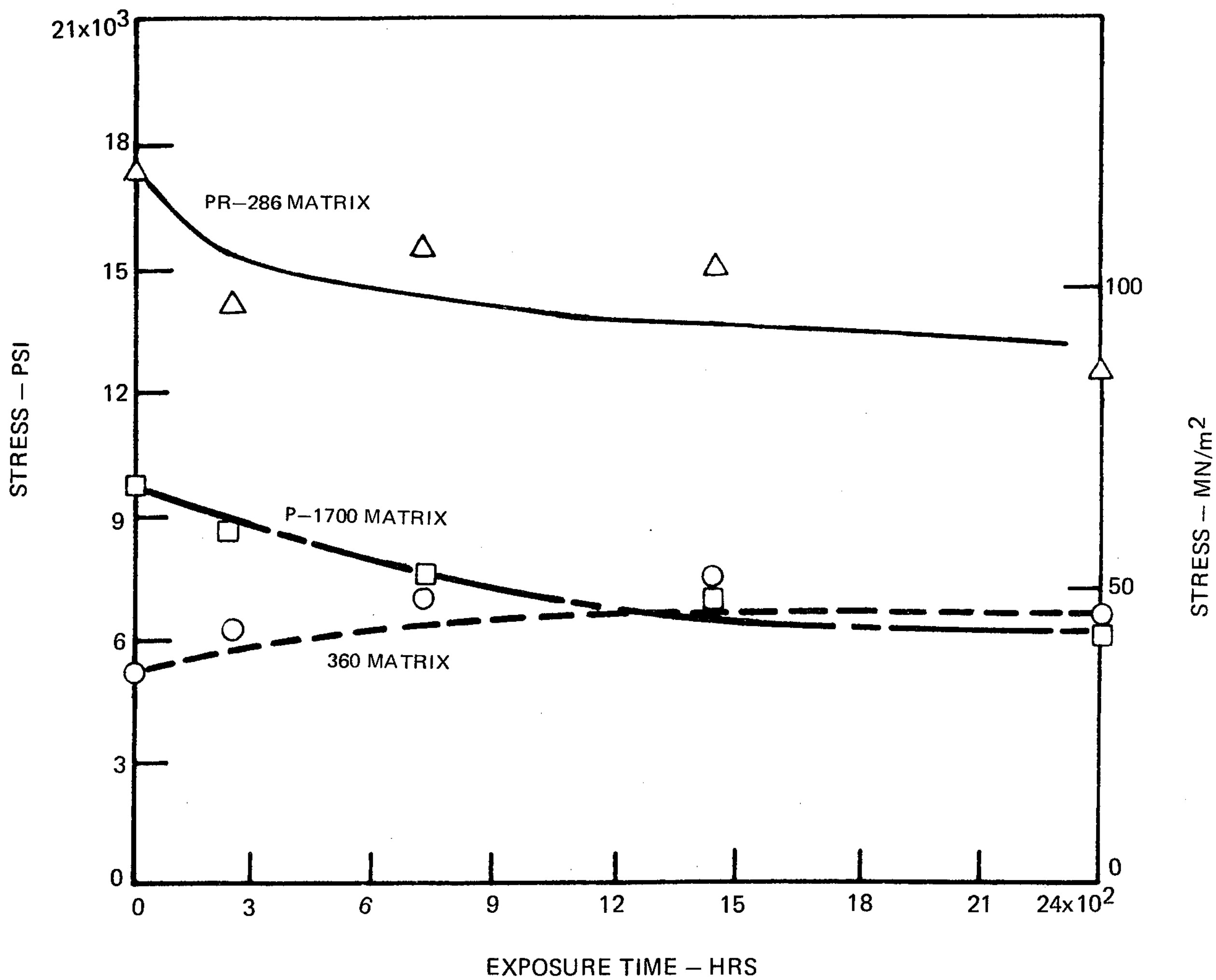
EFFECT OF 177°C EXPOSURE ON –55°C COMPOSITE SHEAR STRENGTH



R07–41–4

FIG. 10

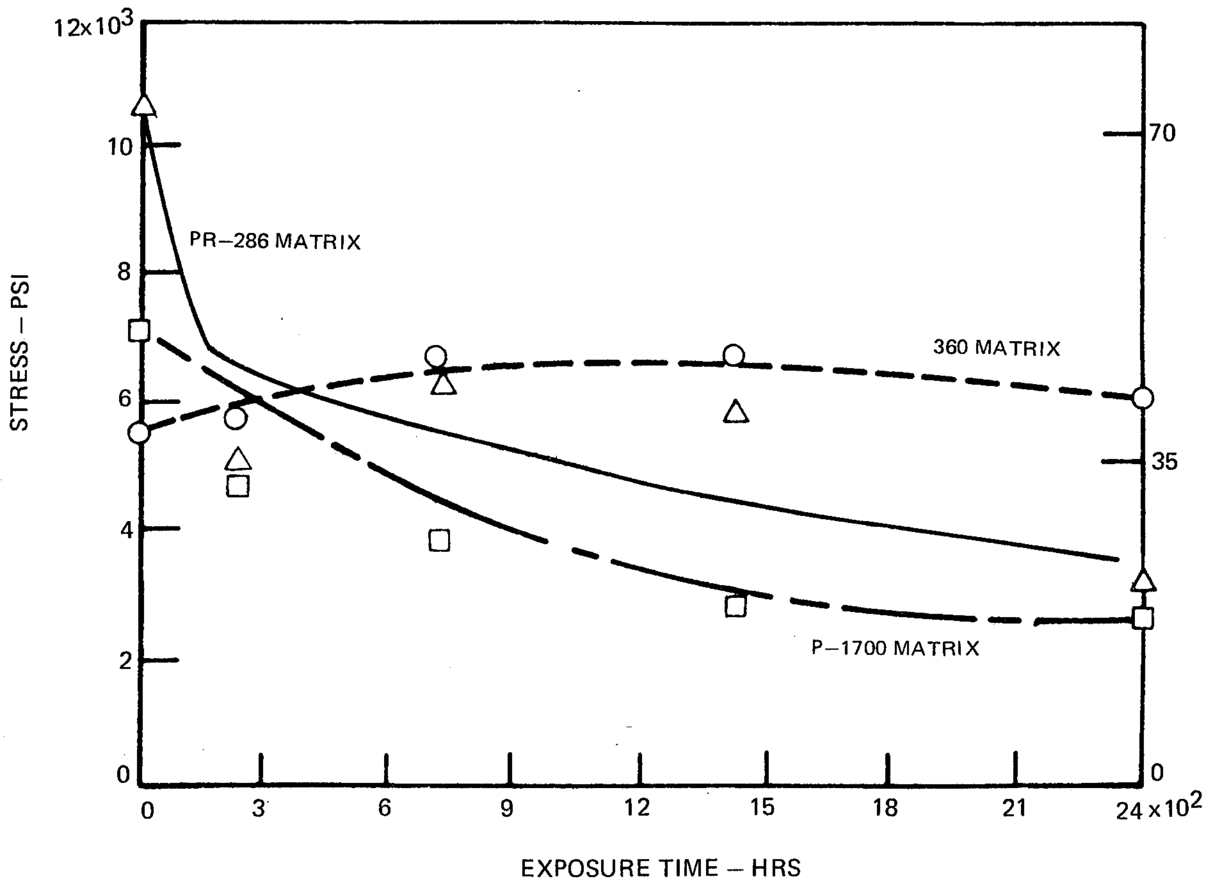
EFFECT OF 177°C EXPOSURE ON 20°C COMPOSITE SHEAR STRENGTH



R07–41–1

FIG. 11

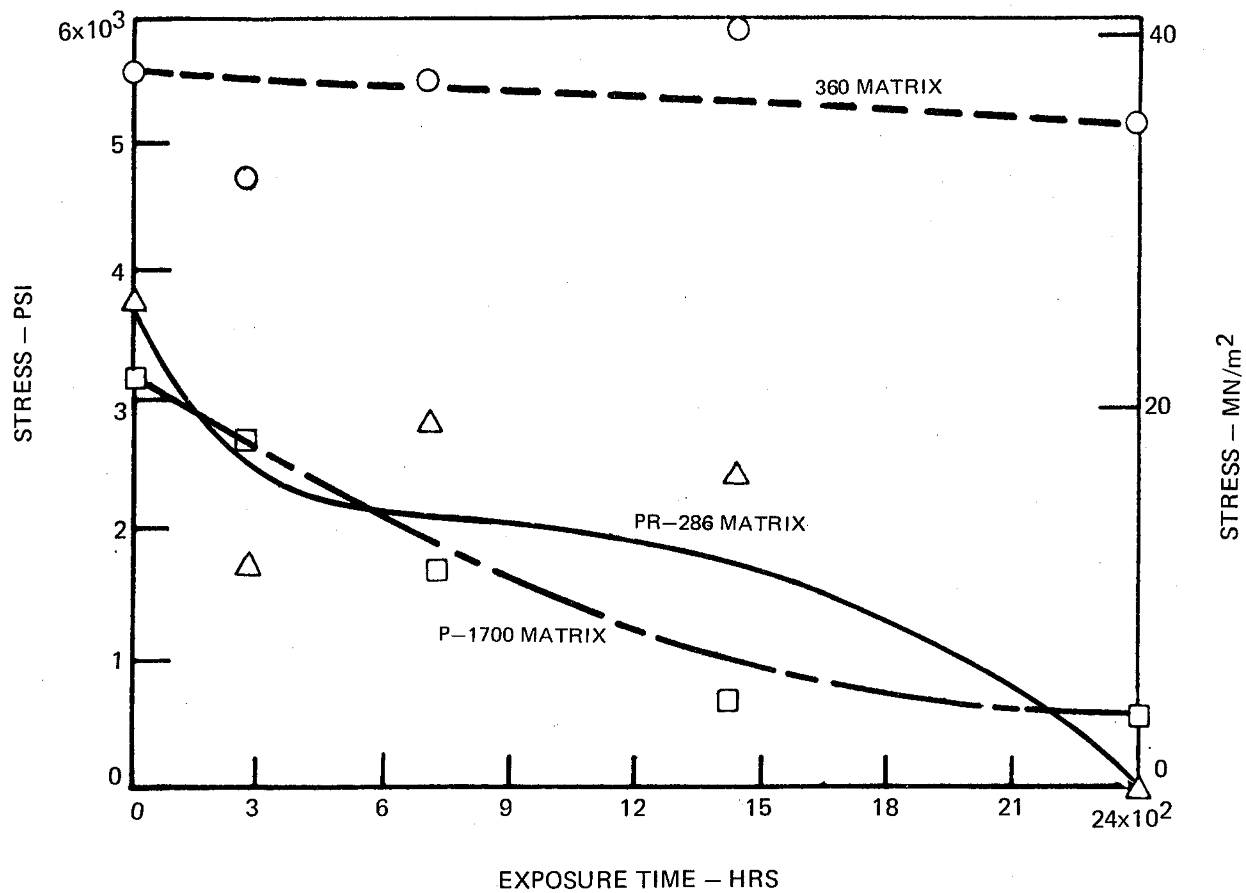
EFFECT OF 177°C EXPOSURE ON 121°C COMPOSITE SHEAR STRENGTH



R07–41–3

FIG. 12

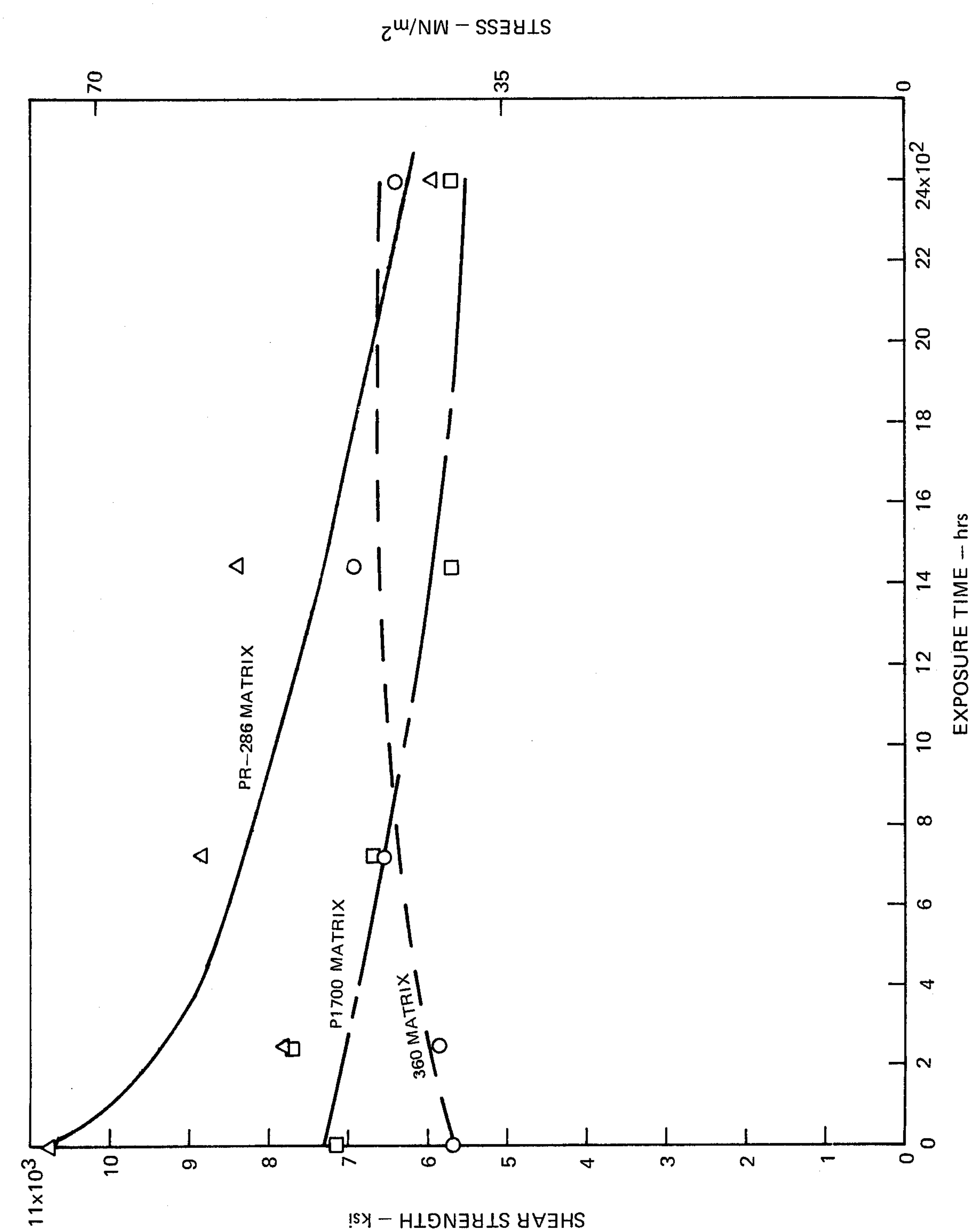
EFFECT OF 177°C EXPOSURE ON 177°C COMPOSITE SHEAR STRENGTH



R07–41–2

FIG. 13

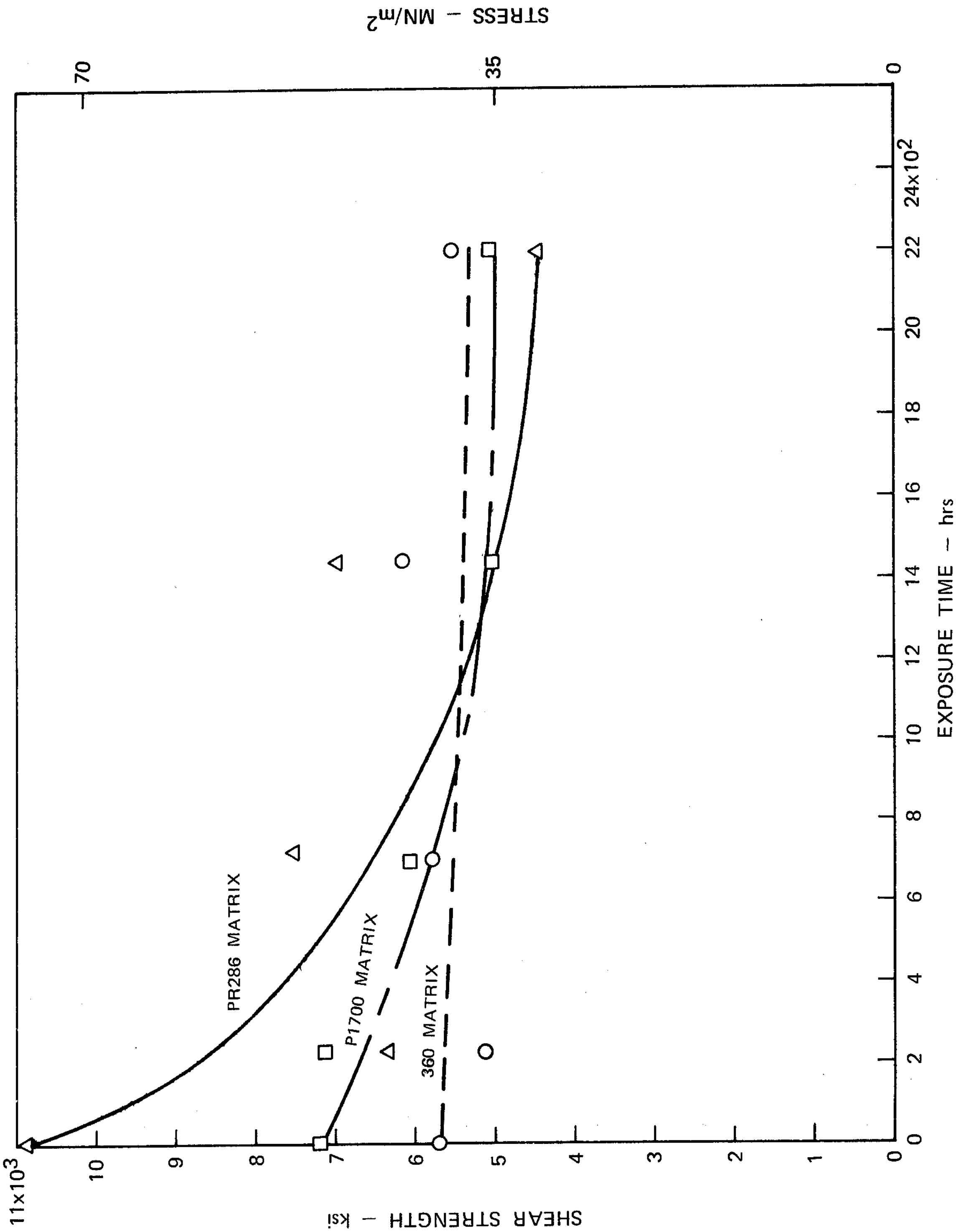
EFFECT OF AMBIENT EXPOSURE ON 121°C COMPOSITE SHEAR STRENGTH



R06–42–5

FIG. 14

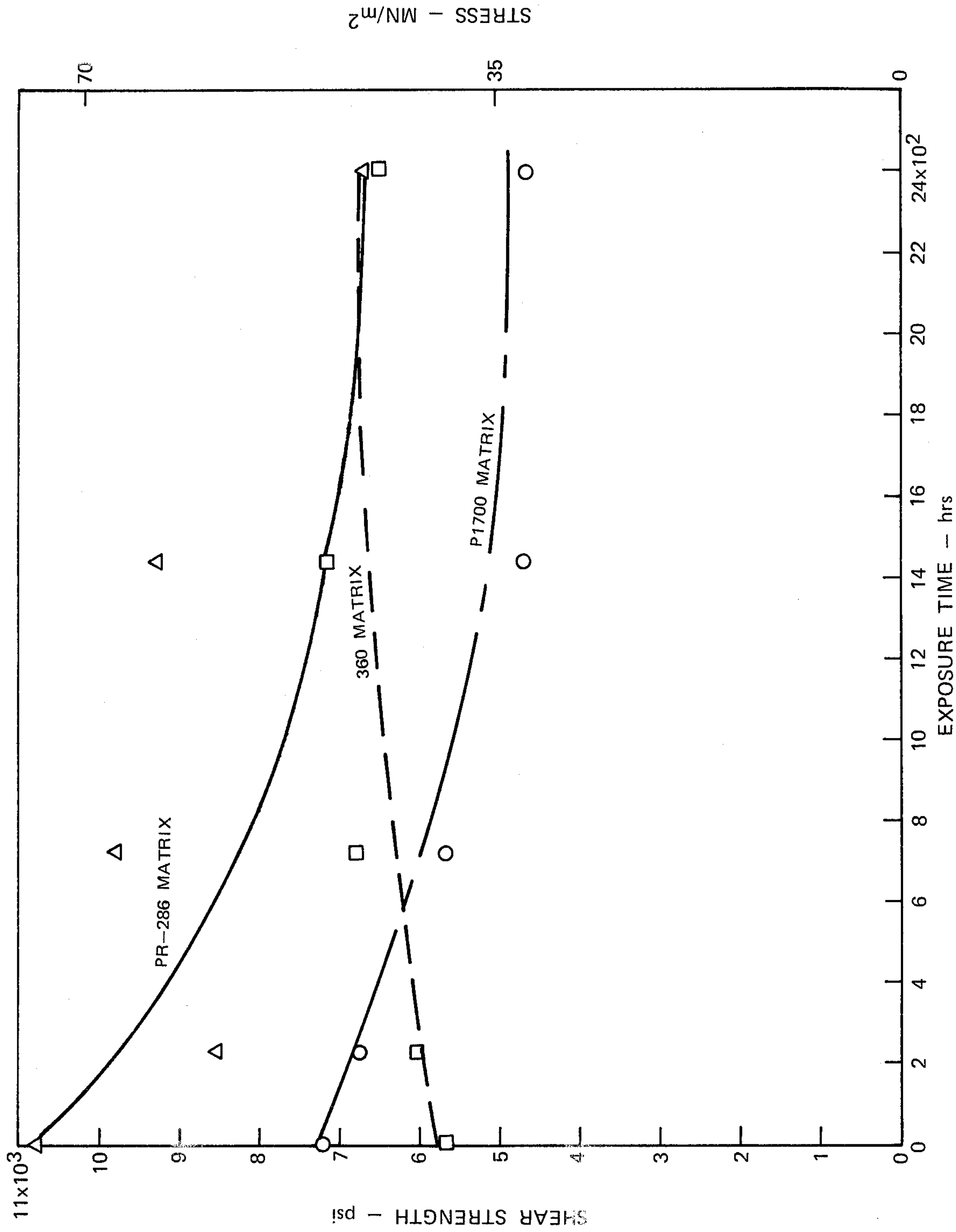
EFFECT OF R.H. AND U.V. AND TEMPERATURE ON 121°C COMPOSITE SHEAR STRENGTH



R06–42–3

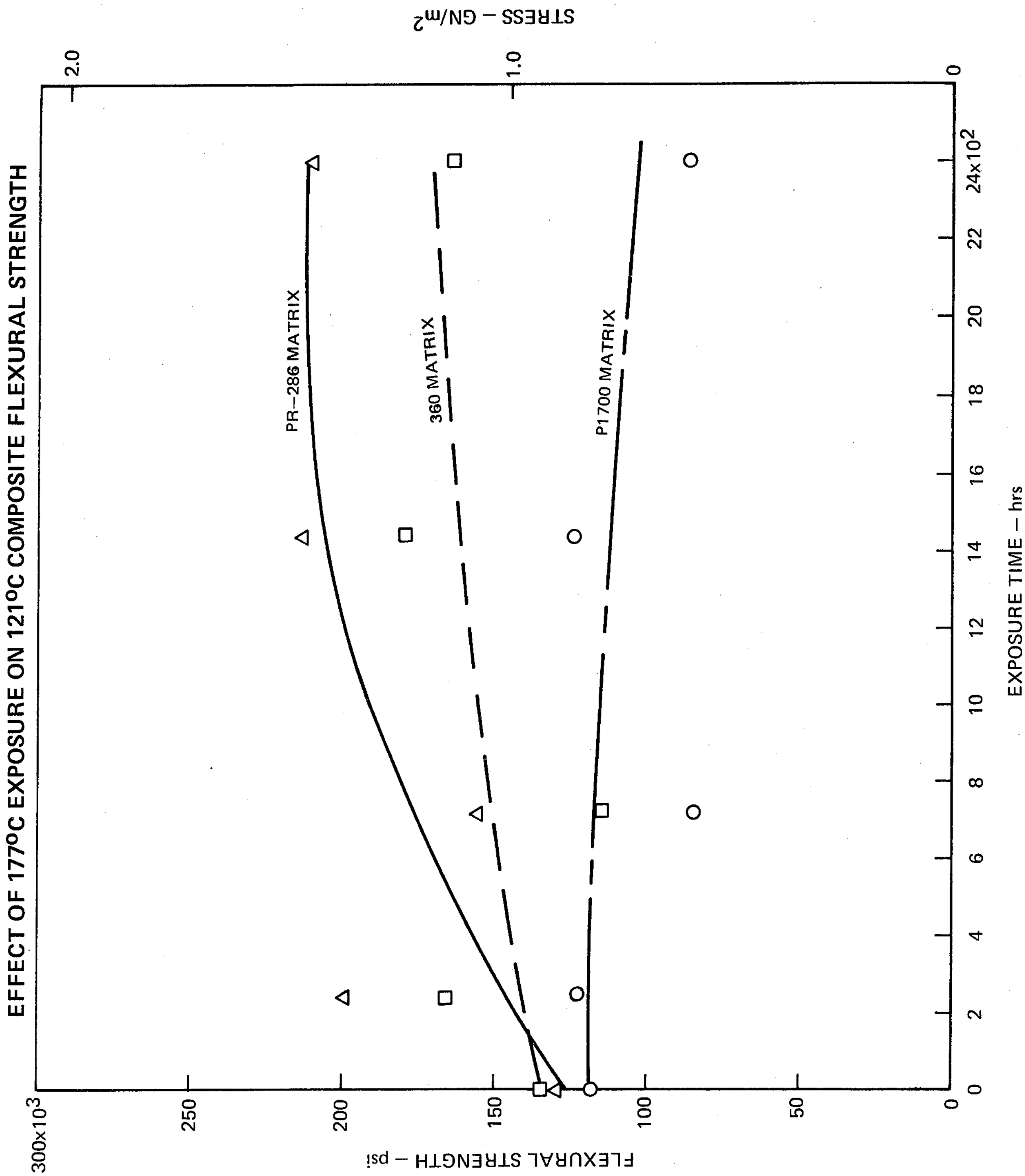
FIG. 15

EFFECT OF 121°C EXPOSURE ON 121°C COMPOSITE SHEAR STRENGTH



R06–42–4

FIG. 16

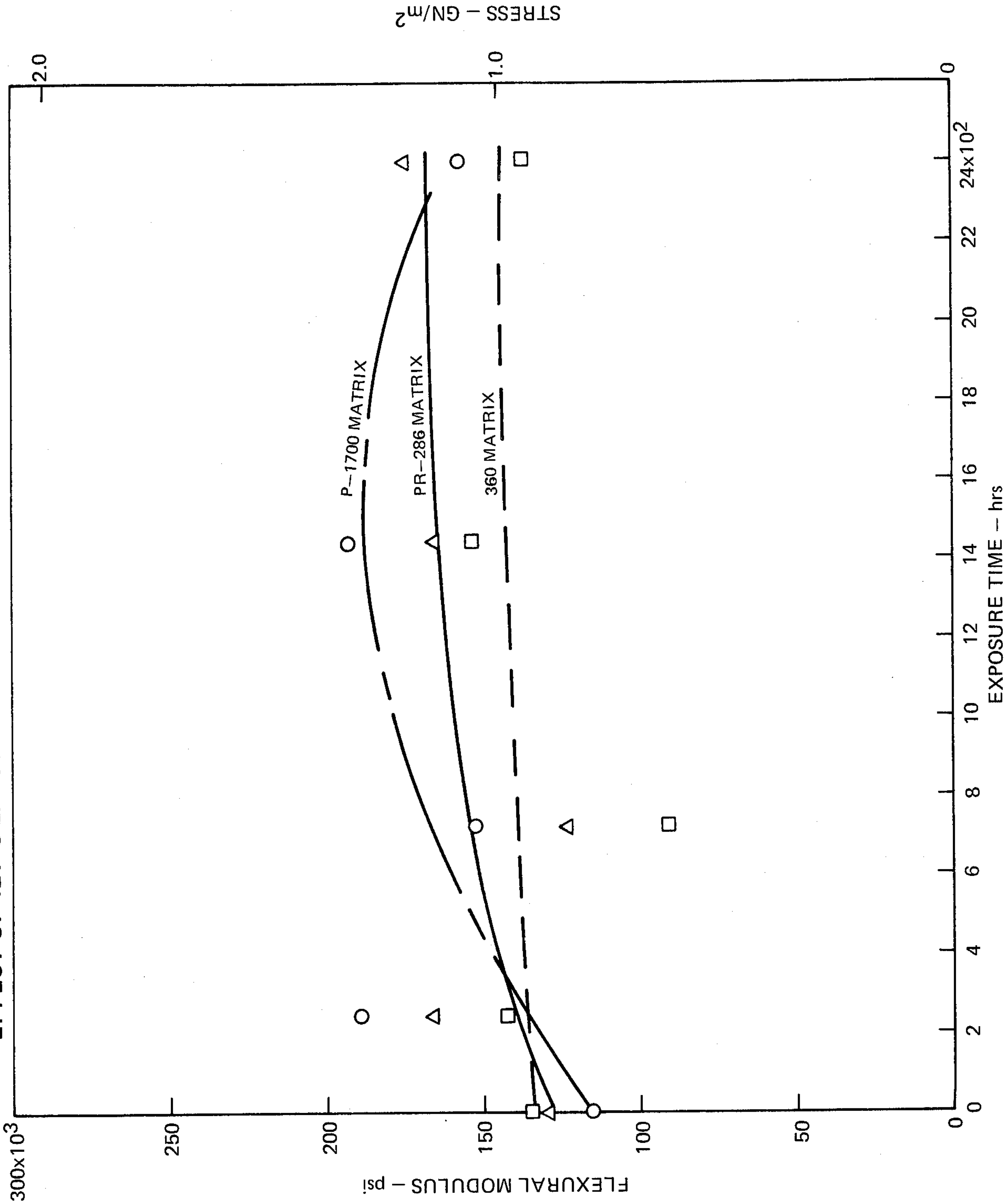


EFFECT OF 177°C EXPOSURE ON 121°C COMPOSITE FLEXURAL STRENGTH
STRESS — GN/m²
2.0
1.0
0
PR–286 MATRIX
360 MATRIX
P1700 MATRIX
300x10³
250
200
150
100
50
0
FLEXURAL STRENGTH — psi
0
2
4
6
8
10
12
14
16
18
20
22
24x10²
EXPOSURE TIME — hrs

R0/-42–2

FIG. 17

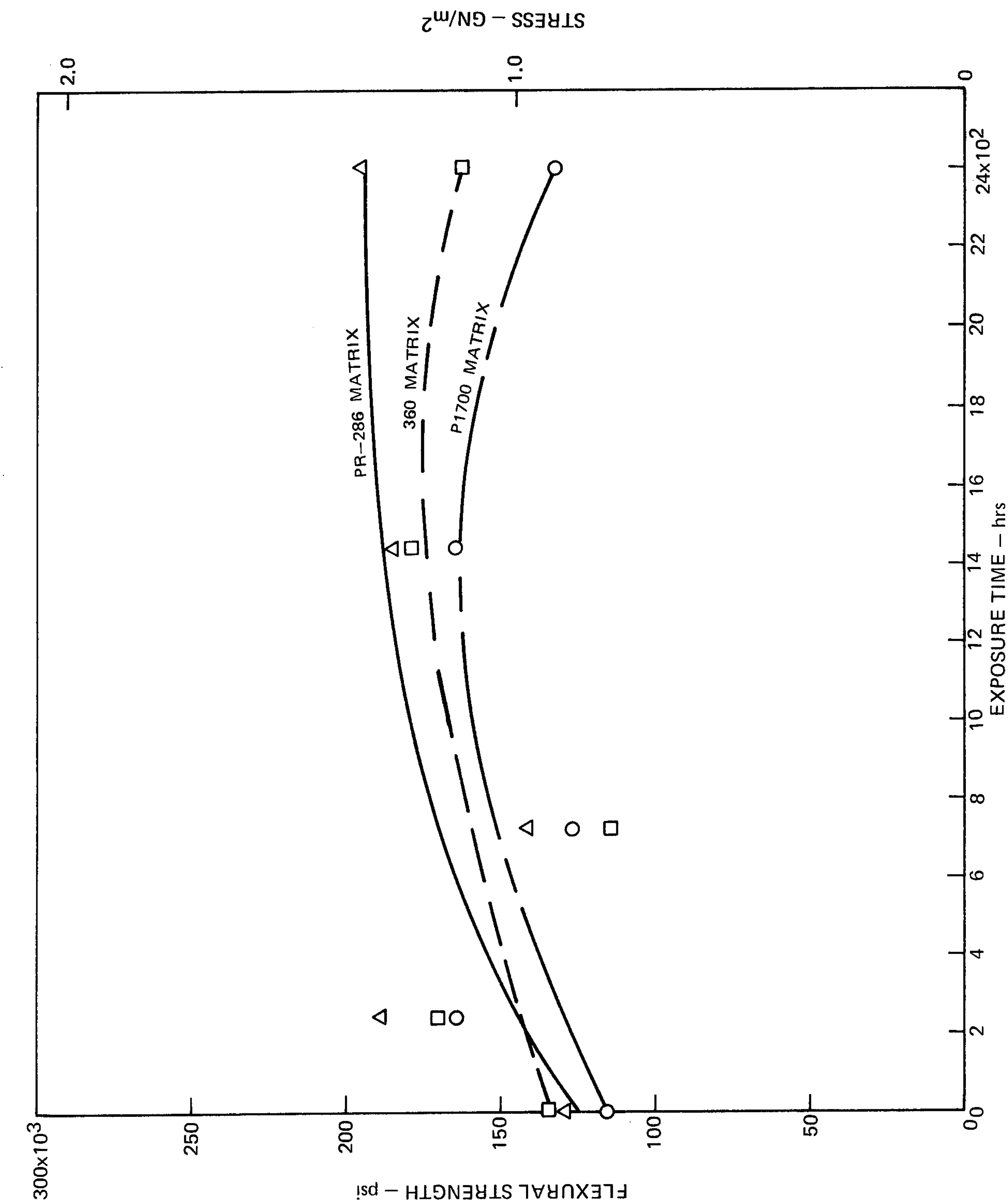
EFFECT OF 121°C EXPOSURE ON 121°C COMPOSITE FLEXURAL STRENGTH



R06–42–10

FIG. 18

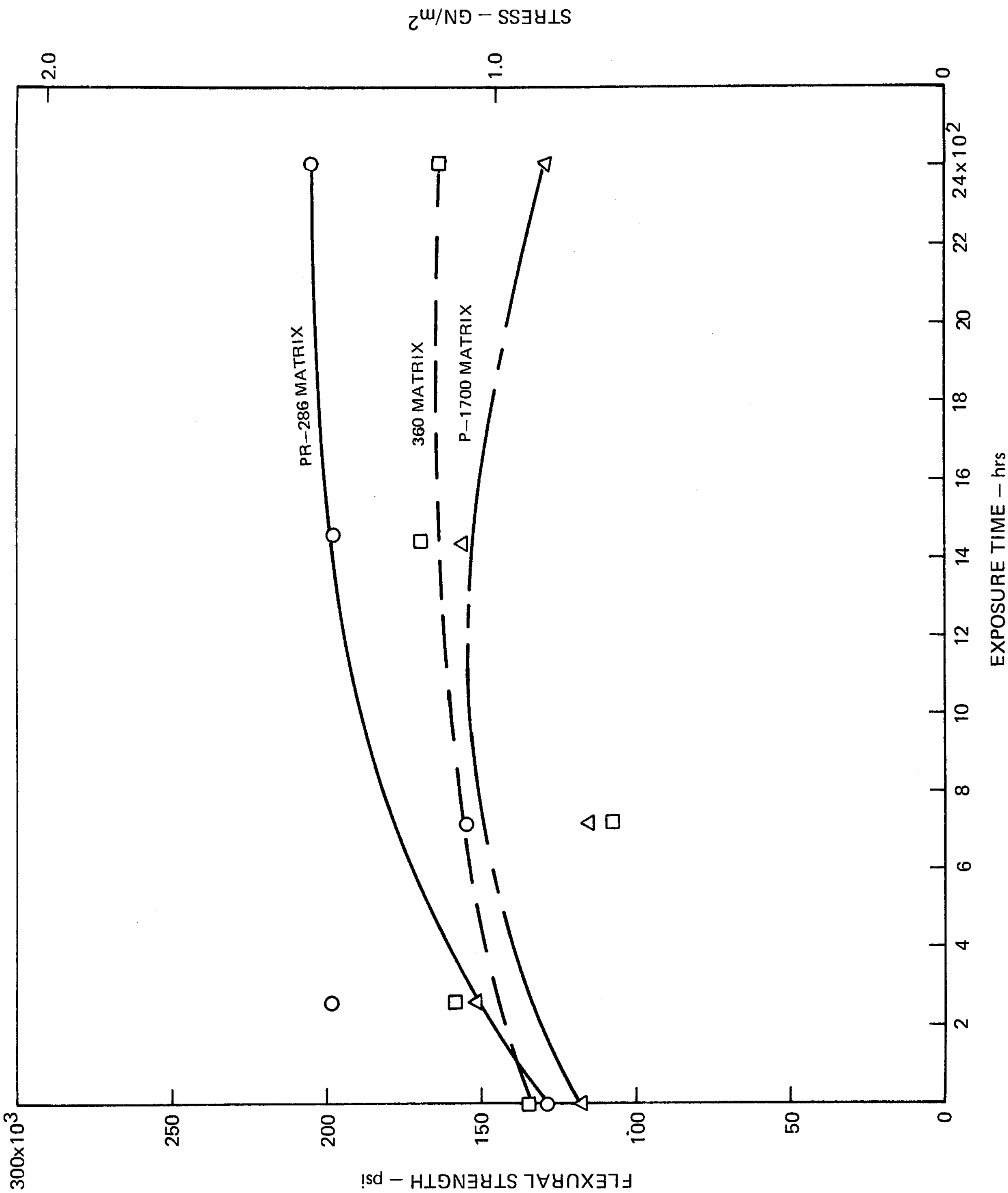
EFFECT OF AMBIENT EXPOSURE ON 121°C COMPOSITE FLEXURAL STRENGTH



R06–42–11

FIG. 19

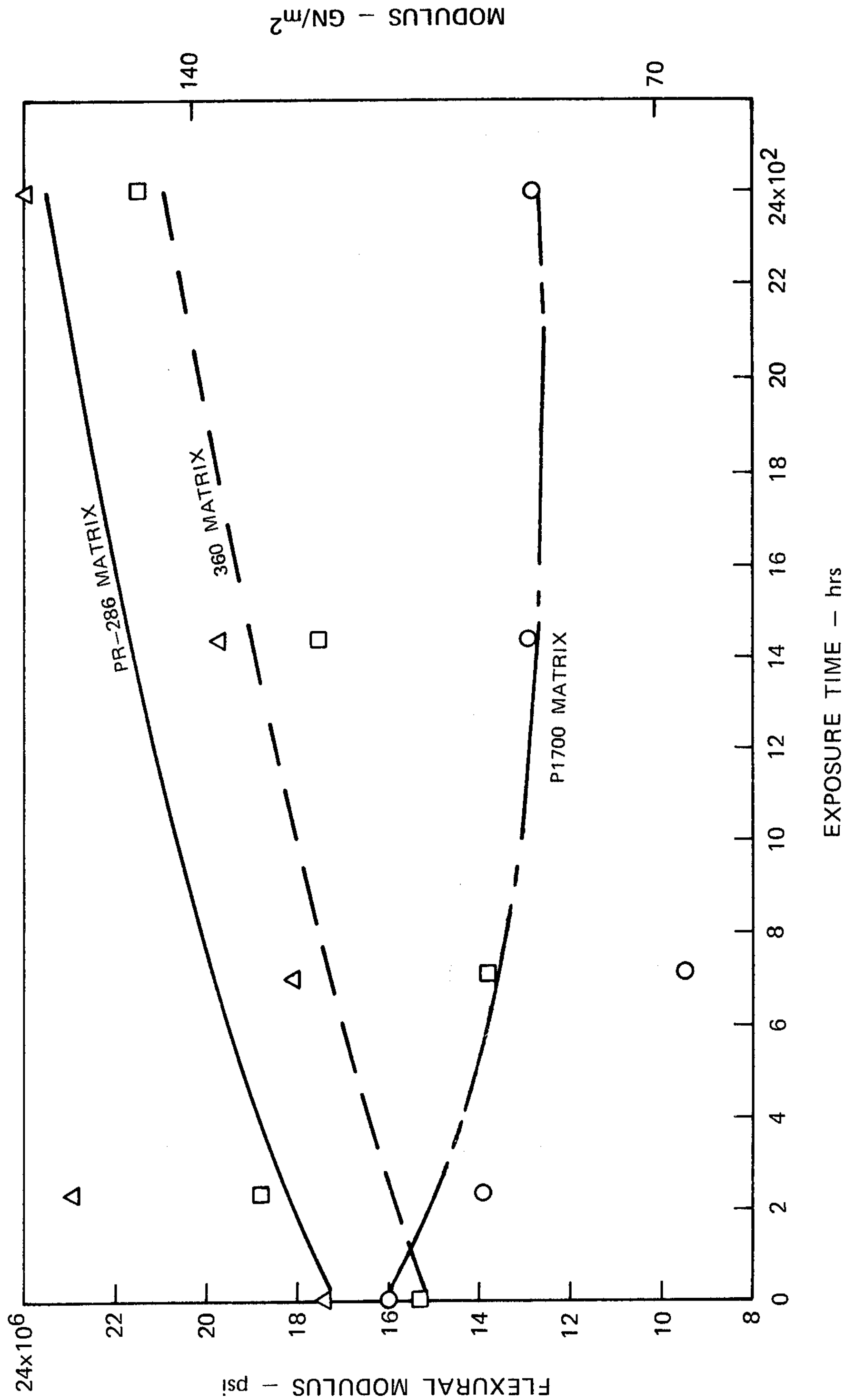
EFFECT OF R.H. AND U.V. AND TEMP. ON 121°C COMPOSITE FLEXURAL STRENGTH



R06–42–7

FIG. 20

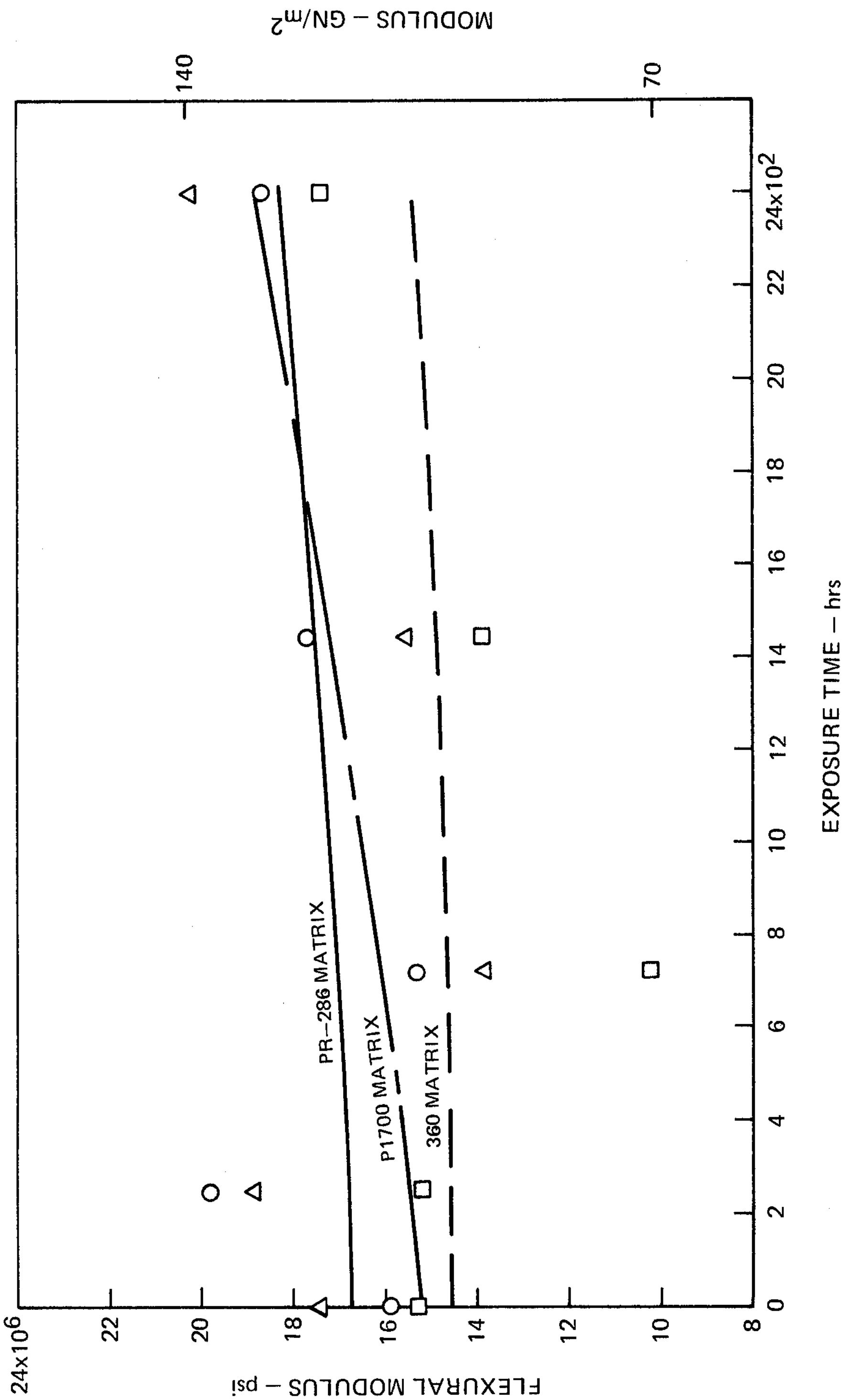
EFFECT OF 177°C EXPOSURE ON 121°C COMPOSITE FLEXURAL MODULUS



R06–42–6

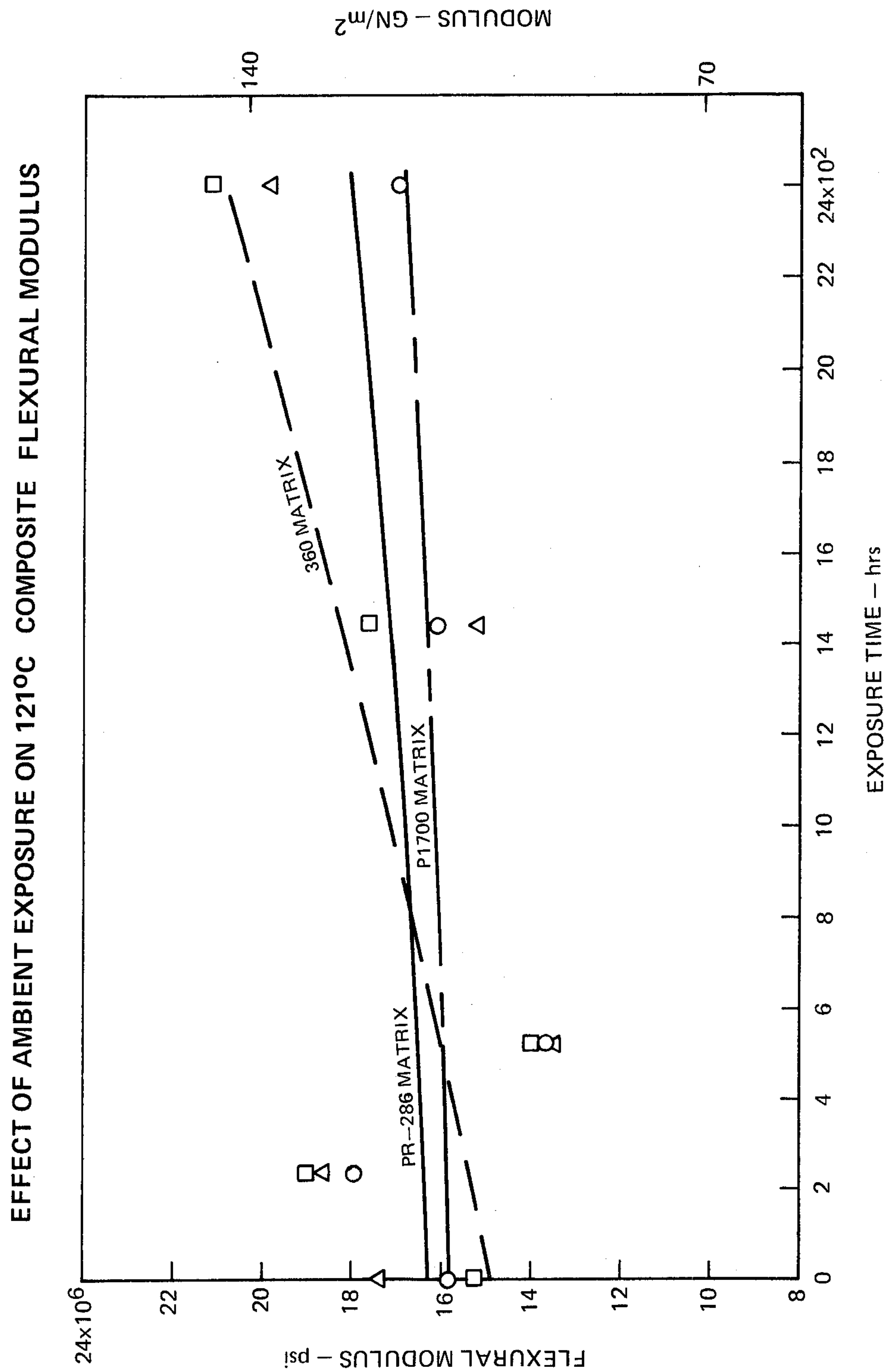
FIG. 21

EFFECT OF 121°C EXPOSURE ON 121°C COMPOSITE FLEXURAL MODULUS



R06–42–9

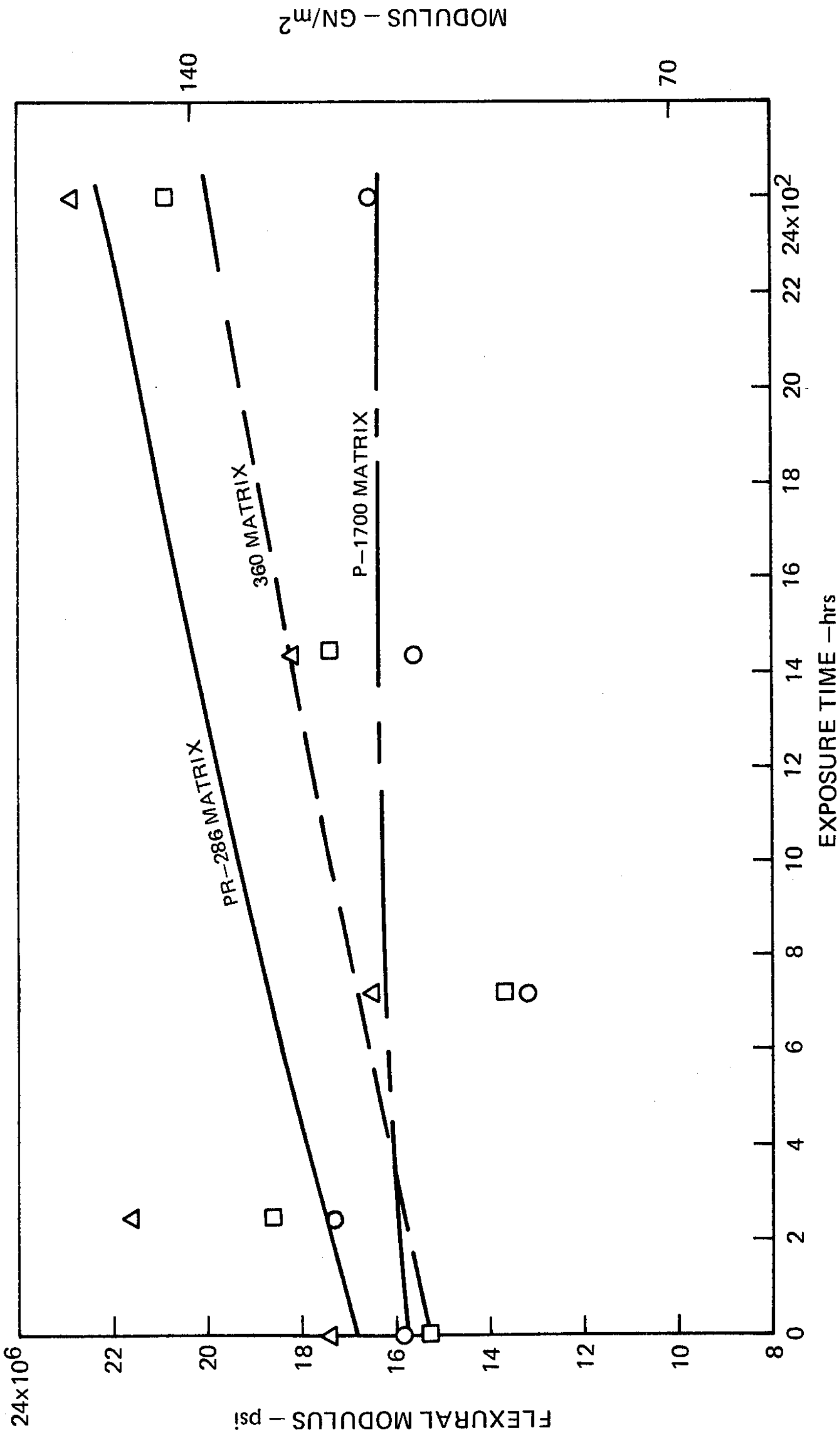
FIG. 22



R06–42–8

FIG. 23

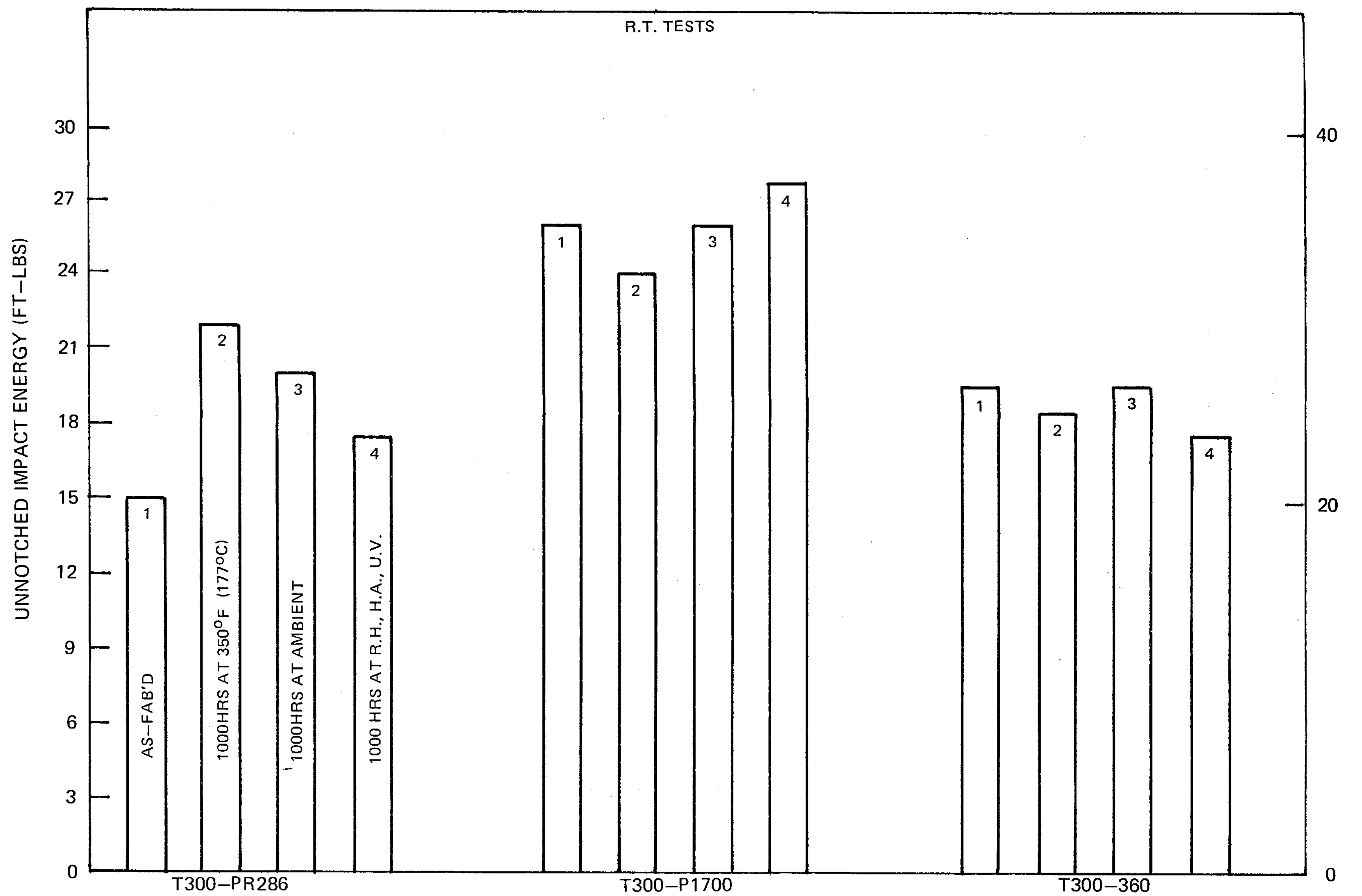
EFFECT OF R.H. AND U.V. AND TEMPERATURE ON 121°C COMPOSITE FLEXURAL MODULUS



R06–42–1

FIG. 24

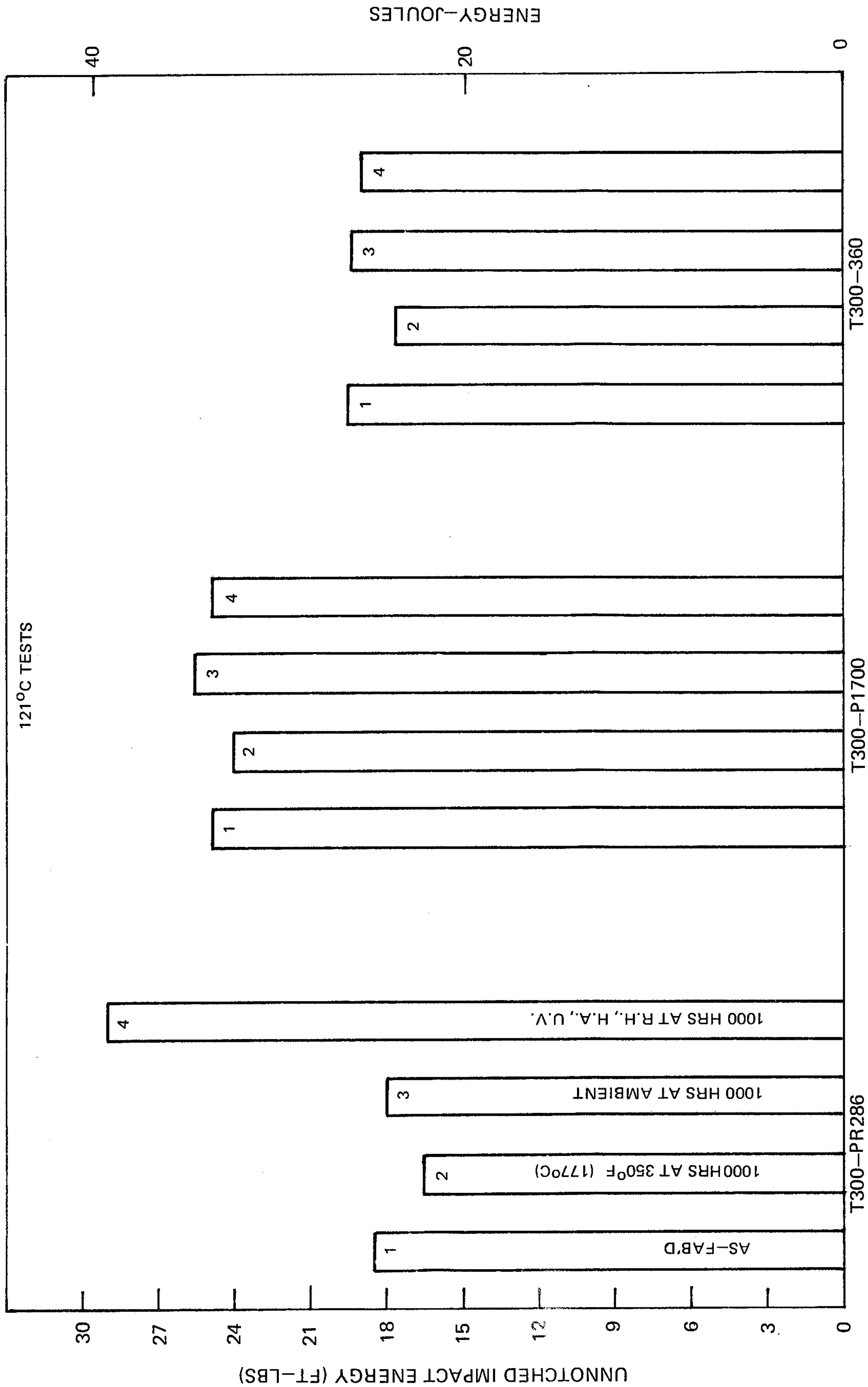
EFFECT OF ENVIRONMENT ON UNNOTCHED COMPOSITE CHARPY IMPACT ENERGY



R06–234–3

FIG. 25

EFFECT OF ENVIRONMENT ON UNNOTCHED COMPOSITE CHARPY IMPACT ENERGY



R06–234–1

INSTRUMENTED PENDULUM IMPACT LOAD–TIME CURVES

T–300/PR–286 CROSS–PLIED COMPOSITES TESTED AT $\pm 45^{o}$

EXPOSED 1000HRS. @R.H., H.A., U.V.

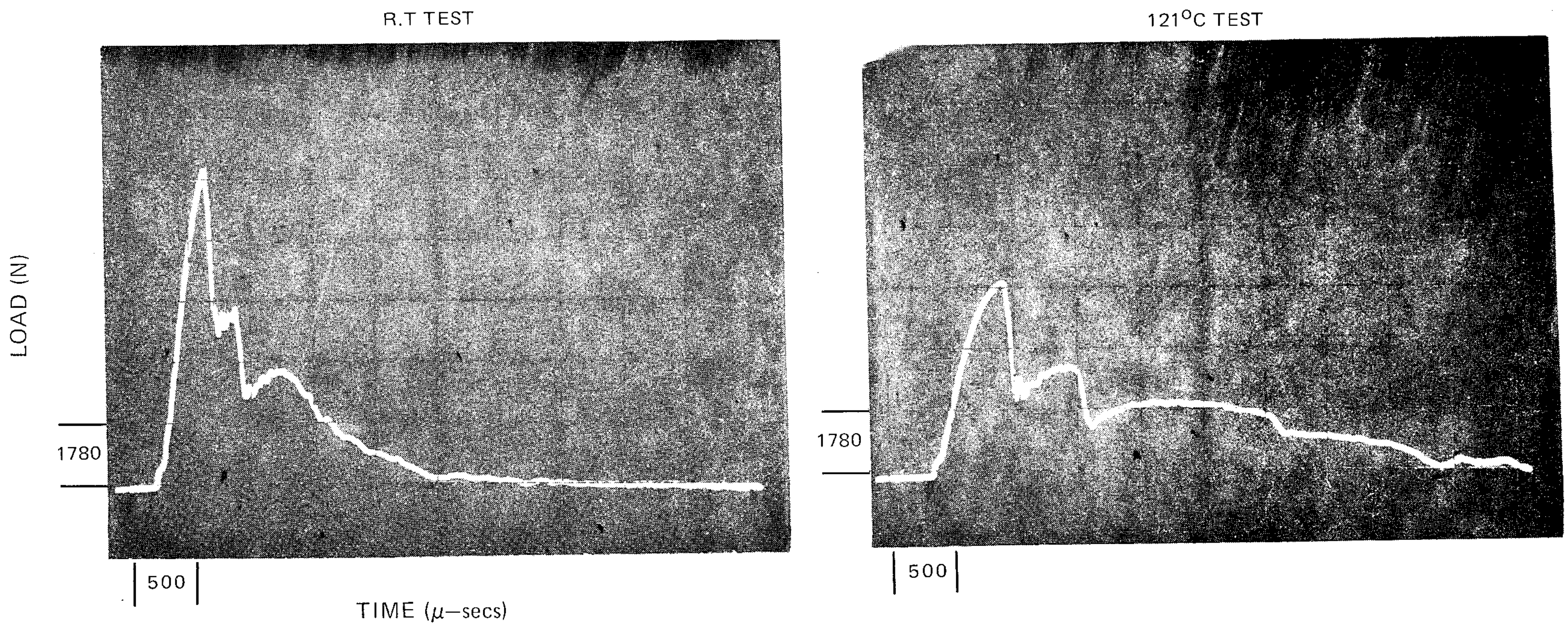


FIG. 26

R10–244–

CREEP OF T300/PR–286 AT 121^{o}C, 60 MN/m^2 (8.7 ksi)
CROSS–PLIED TESTED AT 45^{o}

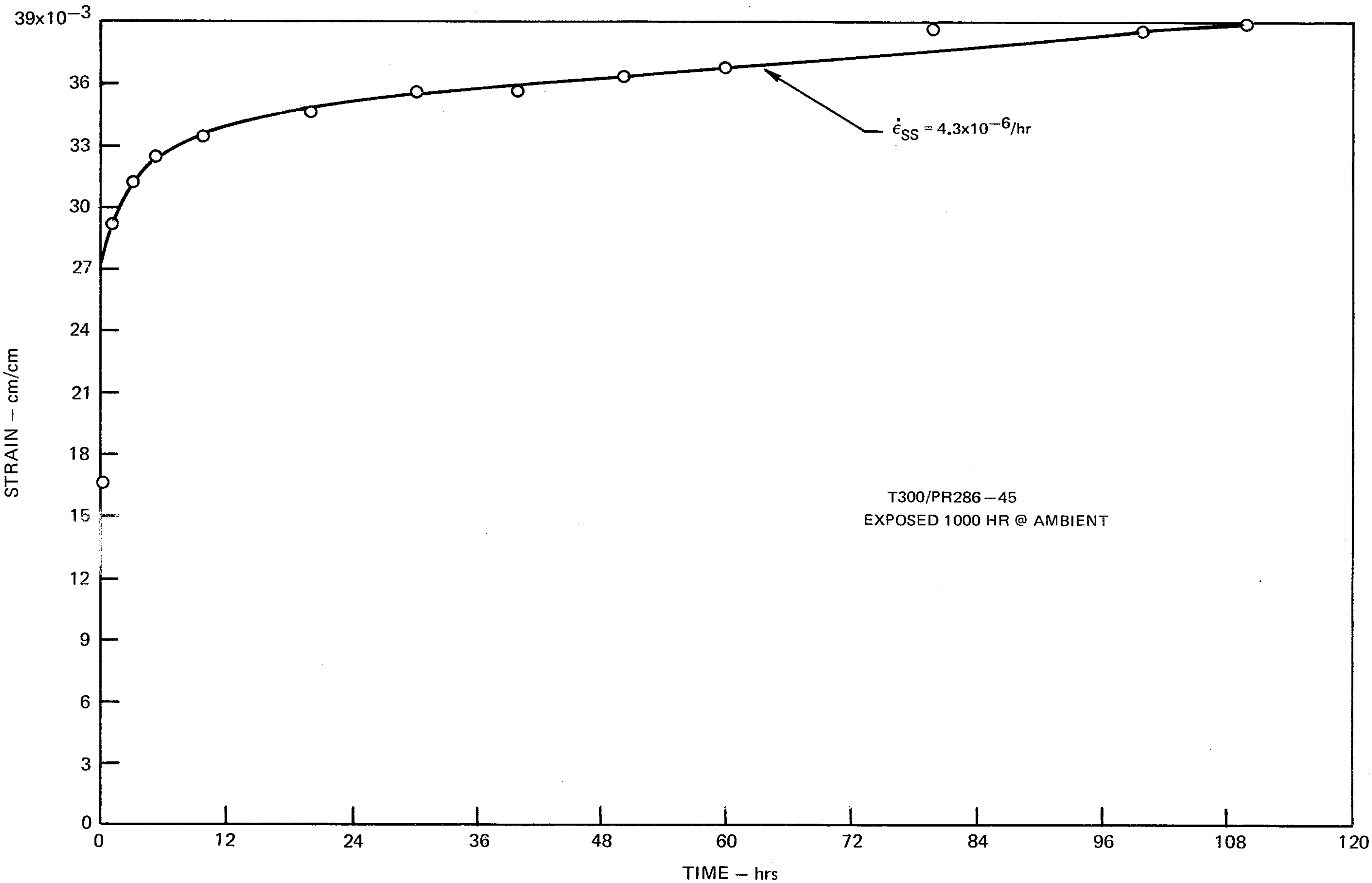
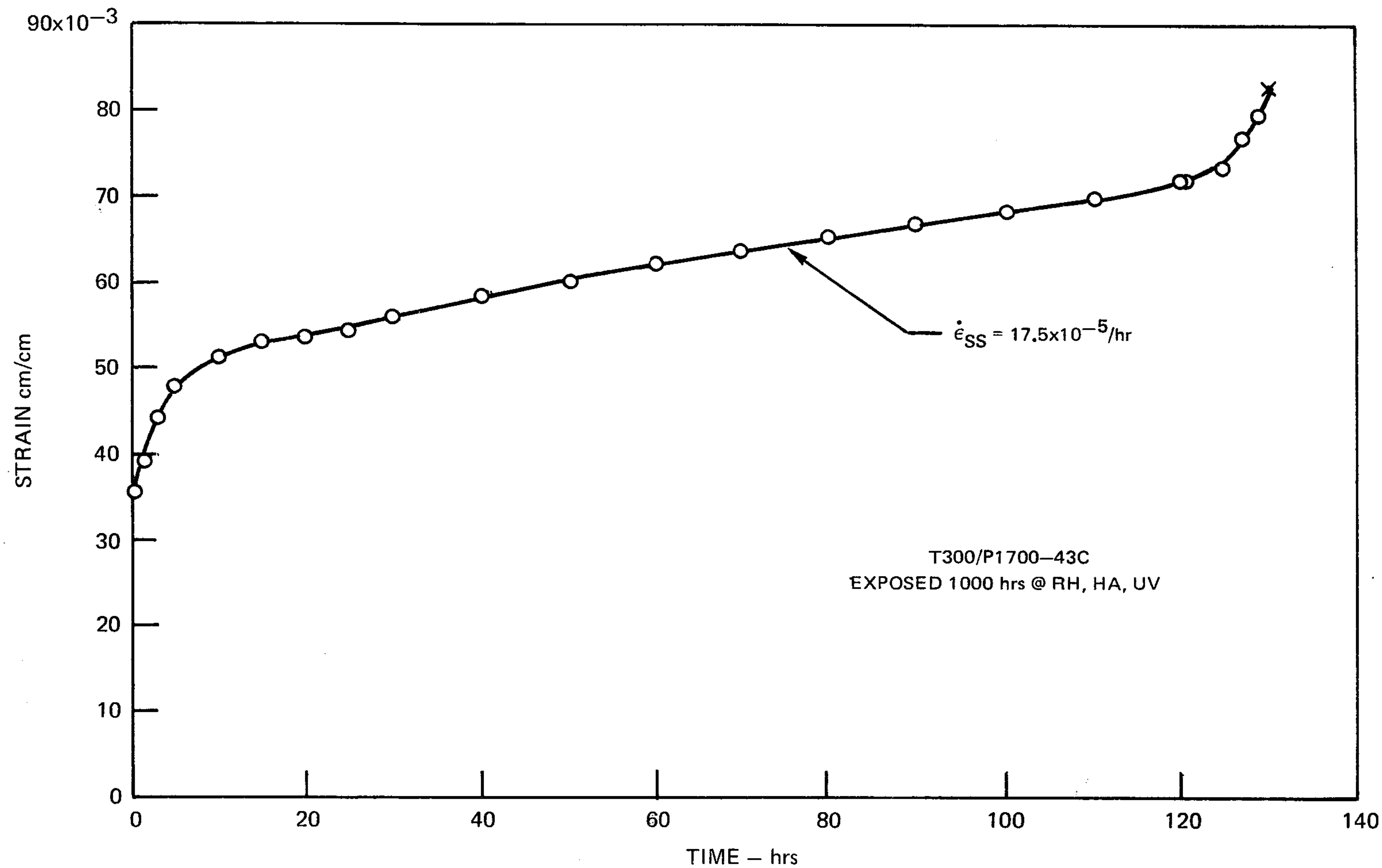


FIG. 27

R07–127–3

FIG. 28

CREEP OF T300/P1700 AT 121°C, 58.6 MN/m² (8.5 ksi)
CROSS–PLIED TESTED AT 45°



R07–127–1

CREEP T300/360 AT 121°C, 52.5 MN/m^2 (7.6 ksi)
CROSS–PLIED TESTED AT 45°

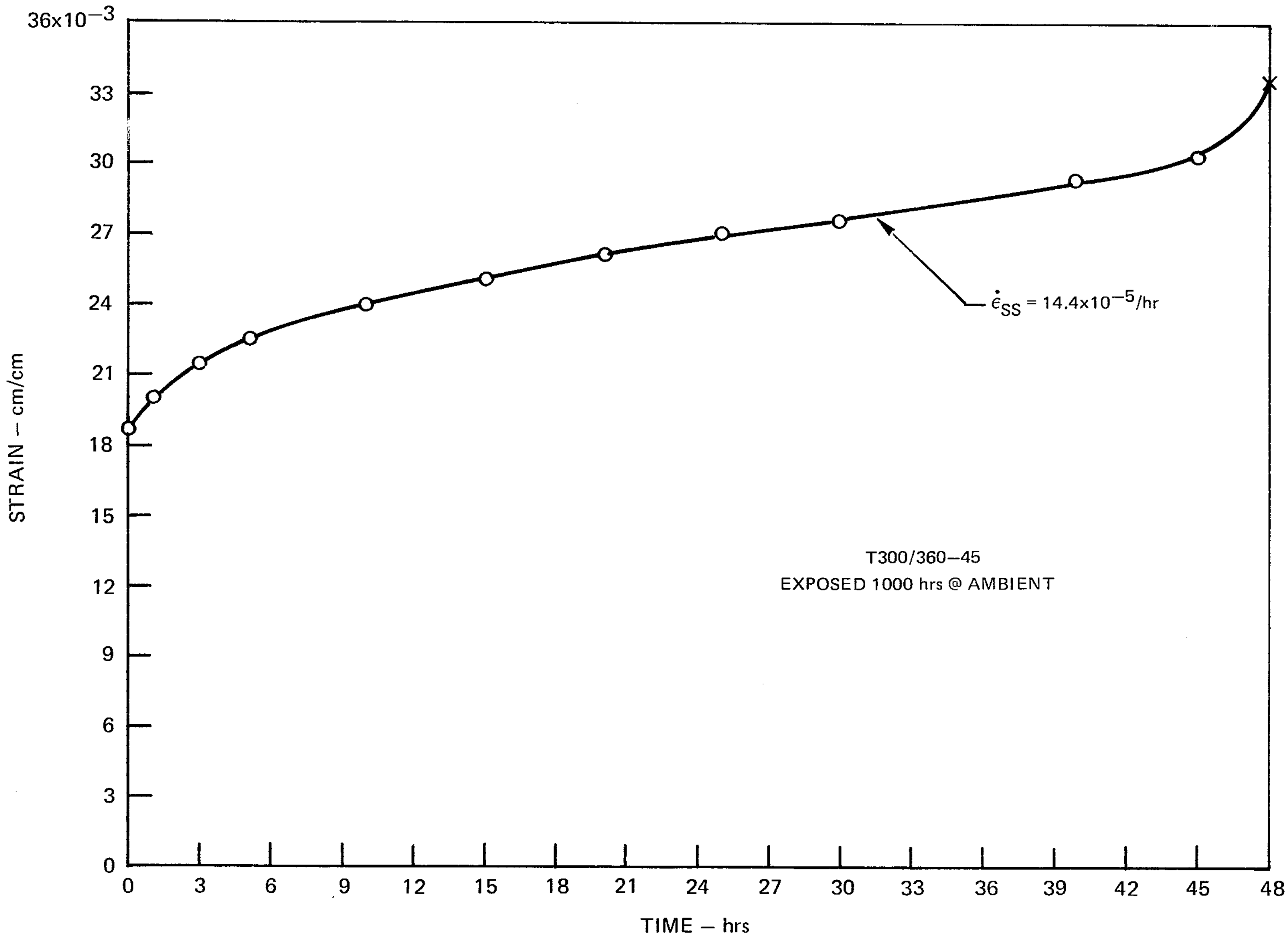
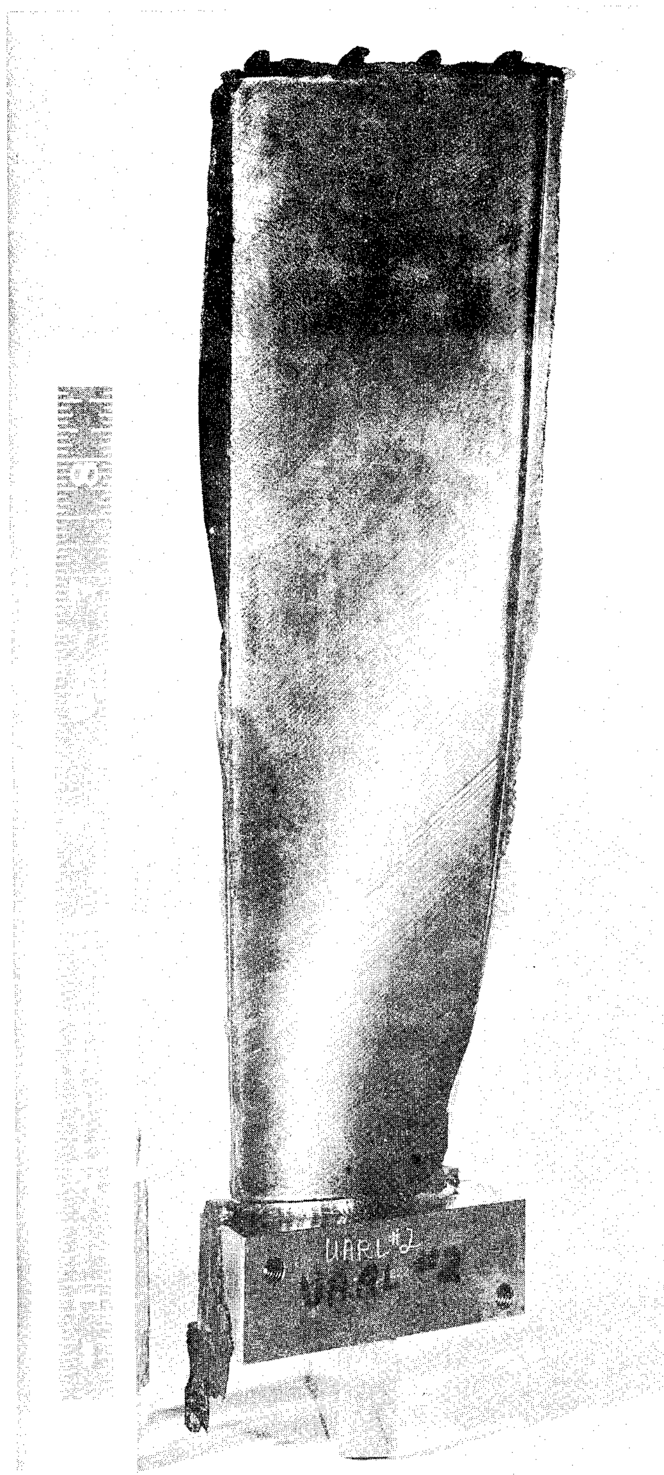


FIG. 29

R07–127–4

FIG. 30

T–300 GRAPHITE /P–1700 POLYSULFONE BLADE AFTER REMOVAL FROM MOLD



R07–116–1

T–300 GRAPHITE /P–1700 POLYSULFONE BLADE AFTER MACHINING

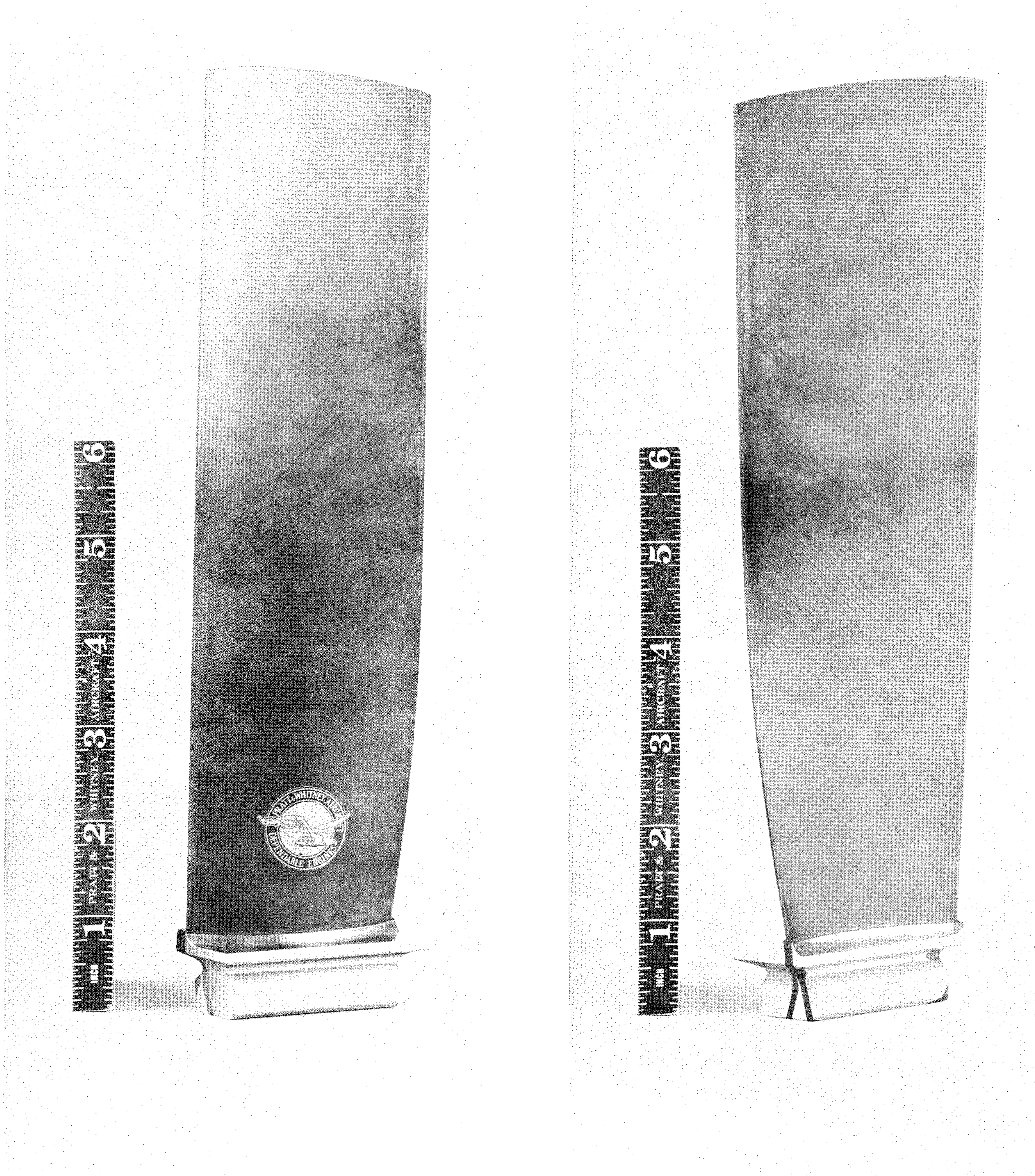
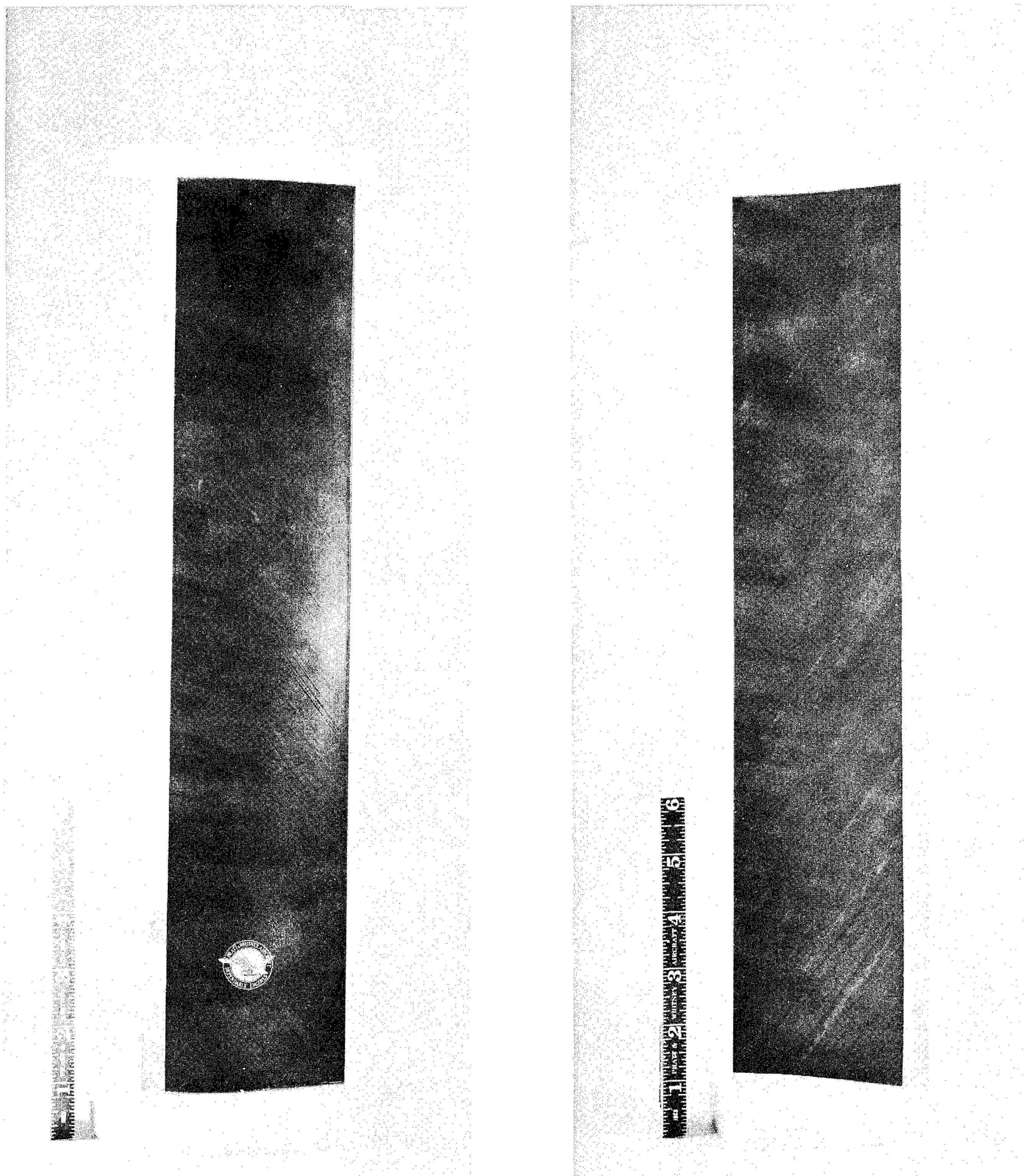


FIG. 32

T–300 GRAPHITE /P–1700 POLYSULFONE FAN EXIT GUIDE VANE



APPENDIX A

RESIN DATA FROM TEST MATRIX

Table A-1

Resin Flexural Strength Measurements
After Environmental Exposure
(MN/m^2)

P-1700

	C_1	C_2	C_3
R_1	T_2 124.1	T_3 122.0	T_1 77.9
R_2	T_1 115.1	T_2 117.9	T_3 106.2
R_3	T_3 0.0	T_1 1.207	T_2 .83

Astrel 360

	C_1	C_2	C_3
R_1	T_1 136.5	T_2 134.5	T_3 111.7
R_2	T_3 100.7	T_1 144.1	T_2 139.3
R_3	T_2 48.3	T_3 46.9	T_1 93.1

PR-286

	C_1	C_2	C_3
R_1	T_3 129.6	T_1 53.1	T_2 183.4
R_2	T_2 119.9	T_3 119.9	T_1 22.1
R_3	T_1 15.9	T_2 17.2	T_3 7.38

Table A-2

Resin Flexural Modulus Measurements
After Environmental Exposure
(GN/m^2)

P-1700

	C_1	C_2	C_3
R_1	T_2 2.48	T_3 2.83	T_1 3.17
R_2	T_1 2.41	T_2 2.62	T_3 2.89
R_3	T_3 0.0	T_1 0.0	T_2 .07

Astrel 360

	C_1	C_2	C_3
R_1	T_1 2.69	T_2 2.83	T_3 3.31
R_2	T_3 3.03	T_1 2.62	T_2 2.55
R_3	T_2 2.27	T_3 1.72	T_1 2.55

PR-286

	C_1	C_2	C_3
R_1	T_3 5.45	T_1 4.96	T_2 5.10
R_2	T_2 3.86	T_3 0.97	T_1 4.48
R_3	T_1 1.45	T_2 0.69	T_3 0.21

Table A-3

Resin Tensile Strength Measurements
After Environmental Exposure
(MN/m^2)

P-1700

	C_1	C_2	C_3
R_1	T_2 57.9	T_3 35.37	T_1 39.51
R_2	T_1 64.8	T_2 48.20	T_3 53.78
R_3	T_3 0.0	T_1 0.0	T_2 0.0

Astrel 360

	C_1	C_2	C_3
R_1	T_1 52.4	T_2 52.20	T_3 55.23
R_2	T_3 38.54	T_1 79.29	T_2 27.03
R_3	T_2 40.00	T_3 27.30	T_1 2.06

PR-286

	C_1	C_2	C_3
R_1	T_3 47.85	T_1 20.20	T_2 22.06
R_2	T_2 33.8	T_3 23.17	T_1 13.24
R_3	T_1 17.79 *	T_2 10.27	T_3 0.69

* Estimated

Table A-4

Resin Tensile Modulus Measurements
After Environmental Exposure
(GN/m^2)

	C_1	C_2	C_3	
R_1	T_2 3.99	T_3 3.31	T_1 3.10	
R_2	T_1 3.31	T_2 3.03	T_3 3.10	P-1700
R_3	T_3 0.0	T_1 0.0	T_2 0.0	

	C_1	C_2	C_3	
R_1	T_1 3.99	T_2 3.17	T_3 3.24	
R_2	T_3 .27	T_1 2.96	T_2 2.83	Astrel 360
R_3	T_2 2.27	T_3 2.07	T_1 2.55 *	

	C_1	C_2	C_3	
R_1	T_3 5.58	T_1 5.38	T_2 5.52	
R_2	T_2 3.65	T_3 4.55	T_1 4.55	PR-286
R_3	T_1 0.41 *	T_2 0.62	T_3 0.0	

* Estimated

APPENDIX B

CALCULATED RESIN PROPERTIES

Table B-1

Effect of 177°C Exposure on Resin
Flexural Strength
(MN/m^2)

177°C Exposure, -55°C Test Temperature

	0	720 hrs.	1440 hrs.	2400 hrs.
P-1700	129.6	104.67	105.29	86.53
360	160.6	135.07	148.38	154.58
PR-286	186.8	92.26	67.23	71.29

177°C Exposure, 20°C Test Temperature

	0	720 hrs.	1440 hrs.	2400 hrs.
P-1700	117.2	109.70	110.32	91.63
360	141.3	135.56	148.86	155.07
PR-286	134.4	57.57	32.48	39.99

177°C Exposure, 177°C Test Temperature

	0	720 hrs.	1440 hrs.	2400 hrs.
P-1700	0	-2.69	-2.07	-20.788
360	63.4	70.26	83.57	89.77
PR-286	17.9	-16.27	-41.37	-33.85

Table B-2

Effect of Ambient Exposure on Resin
Flexural Strength
(MN/m^2)

AMB. Exposure, -55°C Test Temperature

	0	720 hrs.	1440 hrs.	2400 hrs.
P-1700	129.6	120.87	121.49	102.74
360	160.6	117.84	131.14	137.35
PR-286	186.8	168.79	143.76	151.28

AMB. Exposure, 20°C Test Temperature

P-1700	117.2	125.90	126.52	107.77
360	141.3	118.32	131.62	137.83
PR-286	134.4	134.11	109.01	116.52

AMB. Exposure, 177°C Test Temperature

P-1700	0	13.51	14.13	-4.62
360	63.4	53.02	66.33	72.54
PR-286	17.9	60.26	35.16	42.68

Table B-3

Effect of HA, RH, UV Exposure on Resin
Flexural Strength
(MN/m^2)

HA, RH, UV Exposure, -55°C Test Temperature

	0	720 hrs.	1440 hrs.	2400 hrs.
P-1700	129.6	116.39	117.01	98.32
360	160.6	96.94	110.25	116.46
PR-286	186.8	147.55	122.52	130.04

HA, RH, UV Exposure, 20°C Test Temperature

P-1700	117.2	121.42	122.11	103.36
360	141.3	97.35	110.73	116.94
PR-286	134.4	112.87	87.84	95.36

HA, RH, UV Exposure, 177°C Test Temperature

P-1700	0	9.03	9.72	-9.03
360	63.4	32.13	45.44	51.64
PR-286	17.9	39.02	14.00	21.51

Table B-4

Effect of 177°C Exposure on Resin
Flexural Modulus
(GN/m^2)

177°C Exposure, -55°C Test Temperature

	0	720 hrs	1440 hrs	2400 hrs
P-1700	2.28	2.62	2.83	3.03
360	2.55	2.90	2.62	2.90
PR-286	4.20	6.34	5.03	6.07

177°C Exposure, 20°C Test Temperature

	0	720 hrs	1440 hrs	2400 hrs
P-1700	2.62	2.41	2.62	2.83
360	2.69	2.69	2.41	2.69
PR-286	3.10	4.27	2.96	4.00

177°C Exposure, 177°C Test Temperature

	0	720 hrs	1440 hrs	2400 hrs
P-1700	0	-0.14	0	0.21
360	2.28	2.00	1.72	2.00
PR-286	0.28	2.00	0.62	1.65

Table B-5

Effect of Ambient Exposure on Resin Flexural Modulus (GN/m^2)

Ambient Exposure, -55°C Test Temperature

	0	720 hrs	1440 hrs	2400 hrs
P-1700	2.28	2.48	2.69	2.90
360	2.55	2.96	2.69	2.96
PR-286	4.20	5.93	4.62	5.58

Ambient Exposure, 20°C Test Temperature

	0	720 hrs	1440 hrs	2400 hrs
P-1700	2.62	2.28	2.48	2.69
360	2.69	2.83	2.55	2.76
PR-286	3.10	3.86	2.55	3.58

Ambient Exposure, 177°C Test Temperature

	0	720 hrs	1440 hrs	2400 hrs
P-1700	0	-0.28	-0.14	0.07
360	2.28	2.14	1.86	2.14
PR-286	0.28	1.52	0.21	1.24

Table B-6

Effect of HA, RH, UV Exposure on Resin
Flexural Modulus
(GN/m^2)

HA, RH, UV Exposure, -55°C Test Temperature

	0	720 hrs	1440 hrs	2400 hrs
P-1700	2.28	2.69	2.83	3.10
360	2.55	3.10	2.83	3.10
PR-286	4.20	4.90	3.58	4.62

HA, RH, UV Exposure, 20°C Test Temperature

	0	720 hrs	1440 hrs	2400 hrs
P-1700	2.62	2.48	2.69	2.90
360	2.69	2.90	2.62	2.90
PR-286	3.10	2.90	1.52	2.55

HA, RH, UV Exposure, 177°C Test Temperature

	0	720 hrs	1440 hrs	2400 hrs
P-1700	0	-0.14	0.07	0.28
360	2.28	2.21	1.93	2.21
PR-286	0.28	0.55	-0.83	-0.28

Table B-7

Effect of HA, RH, UV Exposure on Resin Tensile Strength (MN/m^2)

HA, RH, UV Exposure, -55°C Test Temp

	0	720 hrs	1440 hrs	2400 hrs
P-1700	76.5	48.33	35.30	38.54
360	56.5	54.19	63.43	38.61
PR-286	50.3	45.09	29.86	23.92

HA, RH, UV Exposure, 20°C Test Temp

	0	720 hrs	1440 hrs	2400 hrs
P-1700	46.2	59.64	46.61	49.85
360	68.3	49.16	58.47	33.65
PR-286	62.7	38.47	23.17	17.31

HA, RH, UV Exposure, 177°C Test Temp

	0	720 hrs	1440 hrs	2400 hrs
P-1700	5.17	4.07	-8.96	-5.72
360	17.9	23.99	33.30	8.48
PR-286	5.17	24.62	9.38	3.52

Table B-8

Effect of 177°C Exposure on Resin
Tensile Strength
(MN/m^2)

	0	720 hrs	1440 hrs	2400 hrs
177°C Exposure, -55°C Test Temp.				
P-1700	76.5	53.37	38.47	43.58
360	56.5	58.40	67.71	42.87
PR-286	50.3	38.27	23.03	17.10
177°C Exposure, 20°C Test Temp.				
P-1700	46.2	64.74	51.64	54.88
360	68.3	53.44	62.68	37.92
PR-286	62.7	31.65	16.34	10.48
177°C Exposure, 177°C Test Temp.				
P-1700	5.17	9.10	-3.93	-0.69
360	17.9	28.27	37.51	12.76
PR-286	5.17	17.79	2.55	-3.31

Table B-9

Effect of Ambient Exposure on Resin
Tensile Strength
(MN/m^2)

Ambient Exposure, -55°C Test Temp.

	0	720 hrs	1440 hrs	2400 hrs
P-1700	76.5	53.99	40.96	44.20
360	56.5	53.57	62.81	37.99
PR-286	50.3	43.23	27.99	22.06
Ambient Exposure, 20°C Test Temp.				
P-1700	46.2	65.30	52.26	55.50
360	68.3	48.54	57.85	33.03
PR-286	62.7	36.61	21.30	15.44
Ambient Exposure, 177°C Test Temp.				
P-1700	5.17	9.72	15.33	-0.07
360	17.9	23.37	32.68	7.86
PR-286	5.17	22.75	7.52	1.65

Table B-10

Effect of HA, RH, UV Exposure on Resin
Tensile Modulus
(GN/m^2)

HA, RH, UV Exposure, -55°C Test Temp.

	0	720 hrs	1440 hrs	2400 hrs
P-1700	3.24	3.65	3.31	3.24
360	3.38	3.52	3.17	3.31
PR-286	5.93	5.38	5.65	5.58

HA, RH, UV Exposure, 20°C Test Temp.

P-1700	3.03	3.31	2.96	2.96
360	2.90	2.96	2.62	2.76
PR-286	4.20	4.00	4.27	4.21

HA, RH, UV Exposure, 177°C Test Temp.

P-1700	0	0.14	-0.14	-0.21
360	2.34	2.34	2.00	2.14
PR-286	3.03	0.14	0.34	0.34

Table B-11

Effect of Ambient Exposure on Resin Tensile Modulus (GN/m^2)

Ambient Exposure, -55°C Test Temp.

	0	720 hrs	1440 hrs	2400 hrs
P-1700	3.24	3.86	3.52	3.45
360	3.38	3.52	3.17	3.31
PR-286	5.93	5.38	5.65	5.58

Ambient Exposure, 20°C Test Temp.

	0	720 hrs	1440 hrs	2400 hrs
P-1700	3.03	3.52	3.24	3.17
360	2.90	2.96	2.62	2.76
PR-286	4.21	4.07	4.27	4.27

Ambient Exposure, 177°C Test Temp.

	0	720 hrs	1440 hrs	2400 hrs
P-1700	0	0.34	0.07	0
360	2.34	2.34	2.00	2.14
PR-286	0.28	0.14	0.41	0.34

Table B-12

Effect of 177°C Exposure on Resin
Tensile Modulus
(GN/m^2)

177°C Exposure, -55°C Test Temp.

	0	720 hrs	1440 hrs	2400 hrs
P-1700	3.24	3.59	3.31	3.24
360	3.38	3.93	3.58	3.72
PR-286	5.93	5.45	5.72	5.65

177°C Exposure, 20°C Test Temp.

P-1700	3.03	3.31	2.96	2.90
360	2.90	3.38	3.03	3.17
PR-286	4.21	4.14	4.41	4.34

177°C Exposure, 177°C Test Temp.

P-1700	0	0.14	-0.14	-0.21
360	2.34	2.76	2.41	2.55
PR-286	0.24	0.21	0.48	0.41

APPENDIX C

COMPOSITE DATA FROM TEST MATRIX

Table C-1

Composite Tensile Strength Measurements
After Environmental Exposure
(MN/m^2)

P-1700 Matrix

	C_1	C_2	C_3	C_4
R_1	T_3 1069	T_4 1248	T_1 1048	T_2 731
R_2	T_1 731	T_2 745	T_4 902.6	T_3 777.8
R_3	T_4 793	T_3 1096	T_2 905.3	T_1 771.6
R_4	T_2 379	T_1 814	T_3 780.5	T_4 419.9

360 Matrix

	C_1	C_2	C_3	C_4
R_1	T_4 1275	T_1 1034	T_2 869	T_3 871.5
R_2	T_2 814	T_4 1172	T_3 276.5	T_1 1107
R_3	T_3 848	T_2 958	T_1 1038	T_4 530.2
R_4	T_1 1220	T_3 855	T_4 785.3	T_2 279.9

PR-286 Matrix

	C_1	C_2	C_3	C_4
R_1	T_2* 835.29	T_3 1469	T_4 931	T_1 1128
R_2	T_3 1124	T_1 1200	T_2 724	T_4 1145
R_3	T_1 800	T_4 883	T_3 932.9	T_2 765
R_4	T_4 422.0	T_2 600	T_1 819.8	T_3 477.8

* Estimated

Table C-2

Composite Tensile Modulus Measurements

After Environmental Exposure
(GN/m^2)

P-1700 Matrix

	C_1	C_2	C_3	C_4
R_1	T_3 111.7	T_4 142.0	T_1 106.2	T_2 123.4
R_2	T_1 99.3	T_2 134.4	T_4 129.6	T_3 133.8
R_3	T_4 113.1	T_3 136.5	T_2 201.3	T_1 94.5
R_4	T_2 111.0	T_1 95.15	T_3 142.7	T_4 109.6

360 Matrix

	C_1	C_2	C_3	C_4
R_1	T_4 133.8	T_1 131.7	T_2 124.8	T_3 130.72
R_2	T_2 146.9	T_4 145.5	T_3 143.4	T_1 128.9
R_3	T_3 138.11	T_2 128.9	T_1 140.7	T_4 138.6
R_4	T_1 145.5	T_3 125.5	T_4 146.2	T_2 122.7

PR-286 Matrix

	C_1	C_2	C_3	C_4
R_1	T_2 97.2	T_3 133.4	T_4 116.5	T_1 139.3
R_2	T_3 118.6	T_1 138.6	T_2 108.9	T_4 118.6
R_3	T_1 127.6	T_4 122.7	T_3 117.2	T_2 137.2
R_4	T_4 76.5	T_2 96.5	T_1 148.9	T_3 117.2

Table C-3

Composite Transverse Tensile Strength Measurements

After Environmental Exposure

(MN/m^2)

P-1700 Matrix

	C_1	C_2	C_3	C_4
R_1	T_3 23.30	T_4 29.0	T_1 11.93	T_2 22.27
R_2	T_1 10.41	T_2 25.86	T_4 28.82	T_3 22.96
R_3	T_4 13.58	T_3 9.6	T_2 10.866	T_1 4.27
R_4	T_2 1.31	T_1 1.048	T_3 1.59	T_4 0

360 Matrix

	C_1	C_2	C_3	C_4
R_1	T_4 15.65	T_1 15.8	T_2 17.65	T_3 13.51
R_2	T_2 16.00	T_4 15.86	T_3 19.17	T_1 3.303
R_3	T_3 12.55	T_2 9.0	T_1* 15.279	T_4 11.24
R_4	T_1 3.72	T_3 5.58	T_4 6.212	T_2* 13.8

PR-286 Matrix

	C_1	C_2	C_3	C_4
R_1	T_2 31.65	T_3 57.9	T_4 14.96	T_1 27.99
R_2	T_3 37.99	T_1 49.0	T_2 41.4	T_4 43.34
R_3	T_1 15.31	T_4 15.9	T_3 24.41	T_2 21.93
R_4	T_4 4.48	T_2 9.7	T_1* 0	T_3 2.048

* Estimated

Table C-4

Composite Transverse Tensile Modulus
Measurements After Environmental Exposure
(GN/m^2)

P-1700 Matrix

	C_1	C_2	C_3	C_4
R_1	J_3 8.41	T_4 8.76	T_1 4.054	T_2 7.79
R_2	T_1 4.76	T_2 8.34	T_4 7.72	T_3 9.03
R_3	T_4 7.03	T_3 5.619	T_2* 0.779	T_1 1.72
R_4	T_2 0.0	T_1 0.786	T_3* 0.359	T_4* 0.0

360 Matrix

	C_1	C_2	C_3	C_4
R_1	T_4 7.65	T_1 6.847	T_2 10.34	T_3 7.72
R_2	T_2 7.38	T_4 8.07	T_3 7.79	T_1 0.0014
R_3	T_3 6.76	T_2 6.723	T_1* 2.586	T_4 0.827
R_4	T_1 7.52	T_3 8.233	T_4* 6.605	T_2* 6.605

PR-286 Matrix

	C_1	C_2	C_3	C_4
R_1	T_2 11.10	T_3 11.93	T_4 8.27	T_1 10.62
R_2	T_3 8.14	T_1 9.38	T_2 9.17	T_4 9.93
R_3	T_1 5.79	T_4 3.17	T_3 4.62	T_2 3.59
R_4	T_4 0.0	T_2 1.062	T_1* 0.634	T_3 0.841

* Estimated

Table C-5

Composite Flexural Strength Measurements
After Environmental Exposure
(MN/m^2)

P-1700 Matrix

	C_1	C_2	C_3	C_4
R_1	T_3 1365	T_4 1358	T_1 724	T_2 1449.3
R_2	T_1 1241	T_2 1310	T_4 731	T_3 1033.6
R_3	T_4 862	T_3 855	T_2 1124	T_1 31.0
R_4	T_2 1111	T_1 120.7	T_3 64.1	T_4 81.4

360 Matrix

	C_1	C_2	C_3	C_4
R_1	T_4 1310	T_1 1345	T_2 1234	T_3 1257.6
R_2	T_2 1055	T_4 1276	T_3 945	T_1 1034
R_3	T_3 1076	T_2 1020	T_1 965	T_4 291.6
R_4	T_1 662.6	T_3 738	T_4 807	T_2 31.0

PR-286 Matrix

	C_1	C_2	C_3	C_4
R_1	T_2 1848	T_3 1834	T_4 1931	T_1 1805.8
R_2	T_3 1896	T_1 1800	T_2 1827	T_4 1834
R_3	T_1 1034	T_4 1034	T_3 1034	T_2 161.3
R_4	T_4 296	T_2 352	T_1 496	T_3 115.1

Table C-6

Composite Flexural Modulus Measurements
After Environmental Exposure
(GN/m^2)

P-1700 Matrix

	C_1	C_2	C_3	C_4
R_1	T_3 118.6	T_4 95.2	T_1 88.3	T_2 135.1
R_2	T_1 100.0	T_2 98.6	T_4 98.6	T_3 100.7
R_3	T_4 119.3	T_3 85.5	T_2 120.7	T_1 0.283
R_4	T_2 17.9	T_1 23.4	T_3 21.4	T_4 18.27

360 Matrix

	C_1	C_2	C_3	C_4
R_1	T_4 126.9	T_1 106.2	T_2 141.3	T_3 113.8
R_2	T_2 107.6	T_4 115.1	T_3 113.1	T_1 122.0
R_3	T_3 124.1	T_2 93.1	T_1 126.9	T_4 52.4
R_4	T_1 86.2	T_3 94.5	T_4 125.5	T_2 2.661

PR-286 Matrix

	C_1	C_2	C_3	C_4
R_1	T_2 133.8	T_3 108.2	T_4 140.0	T_1 139.3
R_2	T_3 141.3	T_1 110.3	T_2 140.0	T_4 146.2
R_3	T_1 133.6	T_4 107.6	T_3 124.1	T_2 49.0
R_4	T_4 61.4	T_2 57.9	T_1 109.6	T_3 40.34

Table C-7

Composite Interlaminar Shear Strength Measurements
After Environmental Exposure
(MN/m^2)

P-1700 Matrix

	C_1	C_2	C_3	C_4
R_1	T_3 90.3	T_4 77.9	T_1 46.9	T_2 77.2
R_2	T_1 52.4	T_2 62.0	T_4 65.09	T_3 68.81
R_3	T_4 44.8	T_3 49.6	T_2 44.61	T_1 7.6
R_4	T_2 12.4	T_1 38.6	T_3 15.9	T_4 18.6

360 Matrix

	C_1	C_2	C_3	C_4
R_1	T_4 46.2	T_1 42.1	T_2 60.0	T_3 50.795
R_2	T_2 49.6	T_4 38.6	T_3 51.0	T_1 47.6
R_3	T_3 44.1	T_2 41.4	T_1 45.5	T_4 40.0
R_4	T_1 40.7	T_3 35.8	T_4 34.5	T_2 35.8

PR-286 Matrix

	C_1	C_2	C_3	C_4
R_1	T_2 147.6	T_3 142.0	T_4 137.62	T_1 63.30
R_2	T_3 115.1	T_1 105.5	T_2 121.97	T_4 104.1
R_3	T_1 60.7	T_4 31.7	T_3 41.4	T_2 57.2
R_4	T_4 16.5	T_2 26.2	T_1 25.5	T_3 30.3

APPENDIX D

CALCULATED COMPOSITE PROPERTIES

Table D-1

Effect of HA, RH, UV Exposure on Composite Longitudinal Tensile Strength

HA, RH, UV Exposure, -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	1027 MN/m^2	956.34	1189.04	1118.92	888.49
360	834	1250.75	1216.28	954.20	908.69
PR-286	1255	949.10	1191.59	1005.84	1033.08

HA, RH, UV Exposure, 20°C Test Temperature

P-1700	927.4	721.42	954.13	887.59	653.58
360	841	1030.72	1046.25	784.17	732.94
PR-286	1106.6	906.35	1148.84	963.09	990.33

HA, RH, UV Exposure, 121°C Test Temperature

P-1700	975.6	823.95	1056.66	990.12	756.11
360	1007	1081.89	1047.42	785.34	739.83
PR-286	1200	703.50	945.99	760.24	787.48

HA, RH, UV Exposure, 177°C Test Temperature

P-1700	251.7	530.78	763.48	696.95	462.93
360	865.3	1023.49	989.02	726.94	681.43
PR-286	607	438.25	680.74	494.99	522.23

Table D-2

Effect of 177°C Exposure on Composite Longitudinal Tensile Strength

177°C Exposure, -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	1027 MN/m^2	956.54	1189.25	1122.71	888.70
360	834	1409.89	1375.41	113.34	1067.83
PR-286	1255	1091.06	1333.56	1147.81	1175.04

177°C Exposure, 20°C Test Temperature

P-1700	927.4	721.63	954.34	887.70	653.78
360	841	1239.86	1205.38	943.30	897.80
PR-286	1106.6	1048.32	1386.86	1105.06	1132.30

177°C Exposure, 121°C Test Temperature

P-1700	975.6	824.16	1056.87	990.12	756.31
360	1007	1241.03	1206.56	944.48	898.97
PR-286	1200	845.46	1290.81	1105.06	929.45

177°C Exposure, 177°C Test Temperature

P-1700	251.7	530.98	763.69	697.15	463.14
360	865.3	1182.63	1148.16	886.08	840.57
PR-286	607	580.21	822.71	636.96	664.20

Table D-3

Effect of 20°C Exposure on Composite Longitudinal Tensile Strength

20°C Exposure -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	1027 MN/m^2	1046.32	1279.02	1212.48	978.47
360	834	1191.25	988.33	726.25	680.74
PR-286	1255	1104.85	1347.35	1161.60	1188.84

20°C Exposure, 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	927.38	811.40	1044.11	977.57	743.56
360	841	852.77	818.30	556.22	510.71
PR-286	1106.6	1062.11	1304.60	118.85	1146.09

20°C Exposure, 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	975.6	913.93	1146.64	1080.10	846.08
360	1007	853.95	819.47	557.39	511.88
PR-286	1200	859.25	1101.75	916.00	943.24

20°C Exposure, 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	251.7	626.76	853.46	786.93	552.91
360	865.3	795.55	761.07	499.20	453.48
PR-286	607	594.00	836.50	650.75	677.98

Table D-4

Effect of 121°C Exposure on Composite Longitudinal Tensile Strength

121°C Exposure, -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1400 hrs	2400 hrs
P-1700	1027 MN/m^2	805.54	1038.25	971.71	737.70
360	834	1409.89	1375.41	113.34	1067.83
PR-286	1255	1091.06	1333.56	1147.81	1175.04

121°C Exposure, 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1400 hrs	2400 hrs
P-1700	927.38	570.63	803.34	736.80	502.78
360	841	1239.86	1205.38	943.30	897.80
PR-286	1106.6	1048.32	1290.81	1105.06	1132.30

121°C Exposure, 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1400 hrs	2400 hrs
P-1700	975.6	673.16	905.86	839.33	605.31
360	1007	1241.03	1206.56	944.48	898.97
PR-286	1200	845.46	1087.96	902.21	929.45

121°C Exposure, 177° Test Temperature

Matrix	0	720 hrs	240 hrs	1400 hrs	2400 hrs
P-1700	251.7	379.98	612.69	546.15	312.14
360	865.3	1182.63	1148.16	886.08	840.57
PR-286	607	580.21	822.71	636.96	664.20

Table D-5

Effect of HA, RH, UV Exposure on Composite Longitudinal Tensile Modulus

HA, RH, UV Exposure -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	131 GN/m^2	105.22	123.42	141.35	111.77
360	145	140.86	132.73	138.52	130.11
PR-286	138	95.84	101.91	101.91	118.87

HA, RH, UV Exposure, R.T. Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	138	108.60	126.80	144.73	115.15
360	138	151.69	143.55	149.35	140.93
PR-286	145	95.36	113.22	113.22	118.39

HA, RH, UV Exposure, 250°F Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	138	120.66	138.86	156.79	127.21
360	145	147.14	139.00	144.80	136.38
PR-286	131	100.32	118.18	118.18	123.35

HA, RH, UV Exposure, 350°F Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	124	99.01	117.21	135.14	105.56
360	145	145.55	137.41	143.21	134.80
PR-286	131	84.05	101.91	101.98	107.08

Table D-6

Effect of 177°C Exposure on Composite Longitudinal Tensile Modulus

177°C Exposure -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	131 GN/m^2	80.40	98.60	116.52	86.94
360	145	136.52	128.38	134.18	125.76
PR-286	138	125.76	143.62	143.62	148.79

177°C Exposure 70°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	138	83.77	101.98	119.90	90.32
360	138	146.93	139.21	145.00	135.59
PR-286	145	125.28	143.14	143.14	148.31

177°C Exposure 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	138	95.84	114.04	131.97	102.39
360	145	142.80	134.66	140.45	132.25
PR-286	131	130.25	148.10	148.10	153.28

177°C Exposure 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	124	74.19	92.39	110.32	80.74
360	145	141.21	133.07	138.86	130.45
PR-286	131	113.97	131.83	131.83	137.00

Table D-7

Effect of 20°C Exposure on Composite
Longitudinal Tensile Modulus

20°C Exposure -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	131 MN/m^2	113.36	131.56	149.48	119.90
360	145	134.38	126.25	132.04	123.63
PR-286	138	108.87	126.73	126.73	131.90

20°C Exposure 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	138	116.11	134.31	152.54	122.66
360	138	145.21	137.07	142.86	134.45
PR-286	145	108.39	126.25	126.25	131.42

20°C Exposure 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	138	128.18	146.38	164.31	134.73
360	145	141.07	132.94	138.73	130.32
PR-286	131	113.35	131.21	131.21	136.38

20°C Exposure 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	124	106.53	124.73	142.66	113.08
360	145	139.07	130.94	136.73	128.32
PR-286	131	97.08	114.94	114.94	120.11

Table D-8

Effect of 121°C Exposure on Composite Longitudinal Tensile Modulus

121°C Exposure -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	131 GN/m^2	124.11	142.31	160.24	130.66
360	145	130.73	122.59	128.38	119.97
PR-286	138	97.22	115.08	115.08	120.25

121°C Exposure 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	138	127.49	145.69	163.62	134.04
360	138	141.55	133.42	139.21	130.80
PR-286	145	96.74	114.59	114.59	119.77

121°C Exposure 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	138	139.55	157.76	175.68	146.10
360	145	137.42	129.28	135.07	126.66
PR-286	131	101.70	119.56	119.56	124.73

121°C Exposure 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	124	117.90	136.11	154.03	124.45
360	145	135.42	127.28	133.07	124.66
PR-286	131	85.43	103.29	103.29	108.46

Table D-9

Effect of HA, RH, UV Exposure on Composite Transverse Tensile Strength

HA, RH, UV Exposure, -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	26.2 MN/m^2	24.48	28.68	25.62	24.68
360	20.0	19.10	14.96	28.55	17.58
PR-286	55.2	25.30	35.99	23.17	26.55
HA, RH, UV Exposure, 20°C Test Temperature					
P-1700	28.3	24.89	29.10	26.06	25.10
360	18.6	10.14	9.72	19.58	8.62
PR-286	43.4	45.58	32.75	32.75	36.13
HA, RH, UV Exposure, 121°C Test Temperature					
P-1700	15.2	12.55	16.75	13.72	12.75
360	11.7	8.55	8.14	18.00	7.03
PR-286	23.4	11.65	22.13	9.52	12.89
HA, RH, UV Exposure, 177°C Test Temperature					
P-1700	0	3.93	8.14	5.10	4.14
360	7.6	3.93	3.52	13.38	2.41
PR-286	7.0	3.72	6.96	5.86	2.48

Table D-10

Effect of 177°C Exposure on Composite Transverse Tensile Strength

177°C Exposure, -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	26.2 MN/m²	13.58	17.79	14.76	13.79
360	20.0	16.41	16.00	25.86	14.89
PR-286	55.2	28.96	39.65	26.82	30.20

177°C Exposure, 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	28.3	14.00	18.20	15.17	14.20
360	18.6	7.45	17.03	16.80	5.93
PR-286	43.4	38.54	49.23	36.40	39.78

177°C Exposure, 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	15.2	1.65	5.86	2.83	1.86
360	11.7	5.86	5.45	15.31	4.34
PR-286	23.4	15.31	25.99	13.17	16.55

177°C Exposure, 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	0	-6.96	-2.8	-5.79	-6.76
360	7.6	1.24	0.83	10.69	-0.28
PR-286	7.0	0.07	10.62	-2.14	1.17

Table D-11

Effect of 20^{o}C Exposure on Composite Transverse Tensile Strength

20^{o}C Exposure, -55^{o}C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	26.2 MN/m^2	20.96	25.17	22.13	21.17
360	20.0	19.58	19.17	29.03	18.06
PR-286	55.2	36.40	47.09	34.37	37.65

20^{o}C Exposure, 20^{o}C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	28.3	21.37	25.58	22.55	21.58
360	18.6	10.62	10.20	20.06	9.10
PR-286	43.4	45.99	56.68	43.85	47.23

20^{o}C Exposure, 121^{o}C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	15.2	9.03	13.24	10.20	9.24
360	11.7	9.03	10.20	18.48	7.52
PR-286	23.4	22.75	33.44	20.62	23.99

20^{o}C Exposure, 177^{o}C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	0	0.41	4.62	1.59	0.62
360	7.6	4.41	4.00	13.86	2.90
PR-286	7.0	7.38	18.06	5.24	8.62

Table D-12

Effect of 121°C Exposure on Composite Transverse Tensile Strength

121°C Exposure, -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	26.2 MN/m^2	21.72	25.92	22.89	21.93
360	20.0	27.79	27.37	37.23	26.27
PR-286	55.2	31.99	42.68	29.86	33.23

121°C Exposure, 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	28.3	22.13	25.17	23.31	22.34
360	18.6	18.82	18.41	28.27	17.31
PR-286	43.4	41.58	52.26	39.44	42.82

121°C Exposure, 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	15.2	9.79	14.00	10.96	10.00
360	11.7	17.24	16.82	26.68	15.72
PR-286	23.4	18.34	29.03	16.20	19.58

121°C Exposure, 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	0	1.17	5.38	2.34	1.38
360	7.6	12.62	12.20	22.06	11.10
PR-286	7.0	2.96	13.65	0.83	4.21

Table D-13

Effect of HA, RH, UV Exposure on Composite Transverse Tensile Modulus

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
HA, RH, UV Exposure -55°C Test Temperature					
P-1700	8.14 GN/m^2	8.76	9.58	6.96	8.34
360	8.171	8.48	8.62	7.93	4.96
PR-286	11.0	9.72	9.86	9.24	9.72
HA, RH, UV Exposure 20°C Test Temperature					
P-1700	8.20	8.96	10.00	6.14	8.55
360	7.79	6.27	6.41	5.72	2.76
PR-286	10.55	8.41	8.55	7.93	8.41
HA, RH, UV Exposure 121°C Test Temperature					
P-1700	7.10	5.31	6.14	3.52	4.90
360	6.69	4.69	4.83	4.14	1.17
PR-286	6.102	3.65	3.79	3.17	3.65
HA, RH, UV Exposure 177°C Test Temperature					
P-1700	0	1.86	2.69	0.07	1.45
360	5.550	7.31	7.45	6.76	3.79
PR-286	0.931	0	0.14	-0.48	0

Table D-14

Effect of 177°C Exposure on Composite Transverse Tensile Modulus

177°C Exposure -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	8.14 GN/m^2	5.72	7.17	3.93	5.31
360	8.171	6.96	7.10	6.41	3.45
PR-286	11.0	10.89	11.00	10.41	10.89

177°C Exposure 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	8.20	7.17	8.00	5.38	6.76
360	7.79	4.76	4.90	4.21	1.24
PR-286	10.55	9.58	9.72	9.10	9.58

177°C Exposure 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	7.10	2.28	3.10	0.48	1.86
360	6.69	3.17	3.31	2.62	-0.34
PR-286	6.102	4.83	4.96	4.34	4.83

177°C Exposure 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	0	-1.17	-0.34	-2.96	-1.58
360	5.550	6.07	6.21	5.52	2.55
PR-286	0.931	1.17	1.31	0.69	1.17

Table D-15

Effect of 20°C Exposure on Composite Transverse Tensile Modulus

20°C Exposure -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	8.14 GN/m^2	8.69	9.52	6.90	8.27
360	8.171	10.27	10.41	9.72	6.76
PR-286	11.0	10.69	10.82	10.20	10.69

20°C Exposure 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	8.20	8.89	9.72	7.10	8.48
360	7.79	8.07	8.21	7.52	4.55
PR-286	10.55	9.38	9.52	8.89	9.38

20°C Exposure 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	7.10	5.24	6.07	3.44	4.83
360	6.69	6.48	6.62	5.93	2.96
PR-286	6.102	4.62	4.76	4.14	4.62

20°C Exposure 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	0	1.79	2.62	0	1.38
360	5.550	9.38	9.52	8.83	5.86
PR-286	0.931	0.96	1.10	0.48	0.97

Table D-16

Effect of 121°C Exposure on Composite Transverse Tensile Modulus

121°C Exposure -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	8.14 GN/m^2	7.17	8.00	5.38	6.76
360	8.171	10.41	10.55	9.86	6.90
PR-286	11.0	10.55	10.69	10.07	10.55

121°C Exposure 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	8.20	7.38	8.21	5.58	6.96
360	7.79	8.21	8.34	7.65	4.69
PR-286	10.55	9.24	9.38	8.76	9.24

121°C Exposure 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	7.10	3.72	4.55	1.93	3.31
360	6.69	6.62	6.76	6.07	3.10
PR-286	6.102	4.48	4.62	4.00	4.48

121°C Exposure 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	0	0.28	1.10	-1.52	-0.14
360	5.550	9.52	9.65	8.96	6.00
PR-286	0.931	0.76	0.90	0.28	7.58

Table D-17

Effect of HA, RH, UV Exposure on Composite
Flexural Strength

HA, RH, UV Exposure, -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	1186 MN/m^2	680.74	946.96	963.16	712.94
360	965	713.01	1072.52	1141.33	1034.40
PR-286	1910	1240.89	1551.44	1537.65	1604.88

HA, RH, UV Exposure, 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	1227	1001.70	1267.92	1284.12	819.61
360	758	853.67	1213.18	1281.99	1175.11
PR-286	1834	1662.11	1972.66	1958.87	2026.10

HA, RH, UV Exposure, 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	814	787.41	1053.62	1072.93	819.61
360	924	744.38	1103.89	1172.70	1065.83
PR-286	889	1064.17	1374.72	1360-94	1428.16

HA, RH, UV Exposure, 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	83	-99.36	166.86	183.06	-67.16
360	817	345.23	704.74	773.55	666.68
PR-286	331	156.52	467.07	453.28	520.50

Table D-18

Effect of 177°C Exposure on Composite Flexural Strength

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
		177°C Exposure, -55°C Test Temperature			
P-1700	1186 MN/M^2	470.91	737.14	753.35	503.13
360	965	773.27	1132.78	1201.54	1094.72
PR-286	1910	1251.10	1561.65	1547.86	1615.08
		177°C Exposure, 20°C Test Temperature			
P-1700	1227	793.13	1055	1075.55	825.33
360	758	913.93	1273.09	1342.25	1235.38
PR-286	1834	1672.31	1982.86	1969.07	2036.30
		177°C Exposure, 121°C Test Temperature			
P-1700	814	578.84	845.05	861.25	611.03
360	924	804.65	1164.15	1232.96	1126.04
PR-286	889	1074.38	1384.93	1468.77	1438.36
		177°C Exposure, 177°C Test Temperature			
P-1700	83	-307.93	-41.71	-25.51	-275.73
360	817	405.49	765.00	833.81	726.94
PR-286	331	166.72	477.27	463.48	530.71

Table D-19

Effect of 20°C Exposure on Composite Flexural Strength

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
20°C Exposure, -55°C Test Temperature					
P-1700	1186 MN/m^2	772.38	1038.59	1054.80	804.58
360	965	775.55	1135.05	1203.87	1096.99
PR-286	1910	1158.22	1468.77	1454.98	1522.21
20°C Exposure, 20°C Test Temperature					
P-1700	1227	1093.34	1359.56	1375.76	1125.54
360	758	916.21	1275.71	1344	1237.65
PR-286	1834	1579.44	1889.99	1876.20	1943.42
20°C Exposure, 121°C Test Temperature					
P-1700	814	879.04	1145.26	1161.46	911.24
360	924	806.92	1166.43	1235.24	1128.37
PR-286	889	981.50	1292.05	1278.26	1345.49
20°C Exposure, 177°C Test Temperature					
P-1700	83	-7.72	258.49	274.70	24.48
360	817	407.77	767.28	836.09	729.22
PR-286	331	73.84	384.40	370.61	437.83

Table D-20

Effect of 121°C Exposure on Composite Flexural Strength

121°C Exposure, -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	1186 MN/m^2	941.44	1207.65	1223.86	973.64
360	965	599.11	958.61	1027.42	920.55
PR-286	1910	1021.84	1332.39	1318.60	1385.83

121°C Exposure, 20°C Test Temperature

P-1700	1227	1262.40	1528.62	1544.82	1294.61
360	758	739.76	1135.05	1168.08	1061.21
PR-286	1834	1443.05	1753.61	1739.82	1807.04

121°C Exposure, 121°C Test Temperature

P-1700	814	1048.11	1314.32	1351.21	1080.31
360	924	630.48	989.98	1058.80	951.92
PR-286	889	845.12	1155.67	1141.88	1209.11

121°C Exposure, 177°C Test Temperature

P-1700	83	161.34	427.56	443.76	193.54
360	817	231.22	590.83	659.64	552.77
PR-286	331	-62.54	248.01	234.22	301.45

Table D-21

Effect of HA, RH, UV Exposure on Composite Flexural Modulus

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
HA, RH, UV Exposure, -55°C Test Temperature					
P-1700	94.5 GN/m^2	59.92	89.64	76.64	82.95
360	101.4	75.98	110.46	101.56	125.97
PR-286	118.6	80.53	114.94	92.26	124.59
HA, RH, UV Exposure, 22°C Test Temperature					
P-1700	122.7	92.39	122.18	109.01	115.49
360	86.9	90.19	124.66	115.77	140.18
PR-286	140.0	117.08	151.48	128.80	161.14
HA, RH, UV Exposure, 121°C Test Temperature					
P-1700	109.6	90.81	120.59	107.42	113.91
360	105.5	94.32	128.80	119.90	144.31
PR-286	120.0	113.42	147.83	125.14	157.48
HA, RH, UV Exposure, 177°C Test Temperature					
P-1700	-	0.14	29.92	16.75	23.24
360	112.4	67.50	101.98	93.08	117.49
PR-286	16.5	53.85	88.26	65.57	97.91

Table D-22

Effect of 177°C exposure on Composite Flexural Modulus

177°C Exposure, -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	94.5 GN/m^2	34.68	64.47	51.30	57.78
360	101.4	76.81	111.28	102.39	126.80
PR-286	118.6	90.88	125.28	102.60	134.94

177°C Exposure, 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	122.7	67.23	97.01	83.84	90.32
360	86.9	91.01	125.49	116.59	141.00
PR-286	140.0	127.76	162.17	139.48	171.82

177°C Exposure, 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P- 1700	109.6	65.64	95.43	82.26	88.74
360	105.5	95.15	129.63	120.73	145.14
PR-286	120.0	124.11	158.52	135.83	168.17

177°C Exposure, 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P -1700	-	25.03	4.76	-8.41	-1.93
360	112.4	68.33	102.80	93.91	118.32
PR-286	16.5	64.54	98.94	76.26	108.60

Table D-23

Effect of 20°C Exposure on Composite Flexural Modulus

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
20°C Exposure, -55°C Test Temperature					
P-1700	94.5 GN/m^2	63.16	92.94	79.78	86.26
360	101.4	77.84	112.32	103.42	127.83
PR-286	118.6	60.26	94.67	71.98	104.32
20°C Exposure, 22°C Test Temperature					
P-1700	122.7	95.70	125.49	112.32	119.42
360	86.9	92.05	126.52	117.63	142.04
PR-286	140.0	96.81	131.21	108.53	140.86
20°C Exposure, 121°C Test Temperature					
P-1700	109.6	94.12	123.90	110.73	117.22
360	105.5	96.32	130.66	121.76	146.17
PR-286	120.0	93.15	127.56	104.87	137.21
20°C Exposure, 177°C Test Temperature					
P-1700	-	3.45	33.23	20.06	26.54
360	112.4	69.36	103.84	94.94	119.35
PR-286	16.5	33.58	67.98	45.30	77.64

Table D-24

Effect of 121°C Exposure on Composite Flexural Modulus

121°C Exposure, -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	94.5 GN/m^2	74.67	104.46	91.29	97.77
360	101.4	52.06	86.53	77.64	102.05
PR-286	118.6	62.61	97.01	74.33	106.66

121°C Exposure, 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	122.7	107.22	137.00	123.83	130.32
360	86.9	66.26	100.74	91.84	116.25
PR-286	140.0	99.15	133.56	110.87	143.21

121°C Exposure, 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	109.6	105.63	135.42	122.25	128.73
360	105.5	70.40	104.87	95.98	120.39
PR-286	120.0	95.50	129.90	107.22	139.55

121°C Exposure, 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P -1700	-	14.96	44.75	31.58	38.06
360	112.4	43.58	77.98	69.16	93.56
PR-286	16.5	35.92	67.98	47.64	79.98

Table D-25

Effect of HA, RH, UV Exposure on Composite Shear Strength

HA, RH, UV Exposure, -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	81.4 MN/m^2	77.98	85.02	71.16	71.09
360	52.5	46.75	41.09	49.30	45.16
PR-286	145.5	126.73	118.18	123.35	105.56

HA, RH, UV Exposure, 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	66.2	66.95	73.98	60.12	60.06
360	36.5	43.71	38.06	46.26	42.13
PR-286	120.0	115.77	107.22	112.39	94.60

HA, RH, UV Exposure, 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	49.6	41.64	48.68	34.82	34.75
360	39.3	39.85	34.20	42.40	38.27
PR-286	74.5	51.92	43.37	48.54	30.75

HA, RH, UV Exposure, 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	22.1	26.34	33.37	19.51	19.44
360	39.3	33.78	28.13	36.34	32.20
PR-286	26.2	28.82	20.27	25.44	7.65

Table D-26

Effect of 177°C Exposure on Composite Shear Strength

177°C Exposure, -55°C Test Temp.

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	81.4 MN/m^2	62.81	69.85	55.99	55.92
360	52.4	50.88	45.23	53.44	49.30
PR-286	145.5	117.97	109.42	114.59	96.81

177°C Exposure, 20°C Test Temp.

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	66.2	51.78	58.81	44.96	44.89
360	36.5	47.85	42.20	50.40	46.26
PR- 286	120.0	107.01	98.46	103.63	85.84

177°C Exposure, 121°C Test Temp.

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	49.6	26.48	33.51	19.65	19.58
360	39.3	43.99	38.34	46.54	42.40
PR-286	74.5	43.16	34.61	39.78	22.00

177°C Exposure, 177°C Test Temp.

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	22.1	11.17	18.20	4.34	4.27
360	39.3	37.92	32.27	40.47	36.34
PR-286	26.2	20.06	11.51	16.68	7.65

Table D-27

Effect of 20°C Exposure on Composite Shear Strength

20°C Exposure, -55°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	81.4 MN/m^2	82.53	89.57	75.71	75.64
360	52.4	52.33	46.68	54.88	50.75
PR-286	145.5	136.38	127.83	133.00	115.22

20°C Exposure, 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	66.2	71.50	78.53	64.68	64.61
360	36.5	49.30	43.64	51.85	47.71
PR-286	120.0	125.42	116.87	122.04	104.25

20°C Exposure, 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	49.6	46.20	53.23	39.37	39.30
360	39.3	45.44	39.99	47.99	43.85
PR-286	74.5	61.57	53.02	58.19	40.40

20°C Exposure, 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	22.1	30.89	37.92	24.06	23.99
360	39.3	39.37	33.72	41.92	37.78
PR-286	26.2	38.47	29.92	35.10	17.31

Table D-28

Effect of 121°C Exposure on Composite Shear Strength

121°C Exposure, -55°C Test Temp.

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	81.4 MN/m^2	75.50	82.53	68.67	68.61
360	52.4	53.57	47.92	56.12	51.99
PR-286	145.5	142.38	133.83	139.00	121.21

121°C Exposure, 20°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	66.2	64.47	71.50	57.64	57.57
360	36.5	50.54	44.89	53.09	48.95
PR-286	120.0	131.42	122.87	128.04	110.25

121°C Exposure, 121°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	49.6	39.16	46.20	32.34	32.27
360	39.3	46.68	41.02	49.23	45.09
PR-286	74.5	67.57	58.74	64.19	46.40

121°C Exposure, 177°C Test Temperature

Matrix	0	720 hrs	240 hrs	1440 hrs	2400 hrs
P-1700	22.1	23.86	30.89	17.03	16.96
360	39.3	40.61	34.96	43.16	39.03
PR-286	26.2	44.47	35.92	41.09	23.31

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